ECONOMIC GEOLOGY

VOL. XXXIV AUGUST, 1939 No. 5

NOMENCLATURE OF THE MEGASCOPIC DESCRIPTION OF ILLINOIS COALS.[1]

GILBERT H. CADY.

ABSTRACT.

The British names vitrain, clarain, and durain and the more commonly used name fusain have been adopted by the Illinois State Geological Survey as an aid in the megascopic description of the material composing the coal beds of the Illinois coal basin. Expanding activities in our laboratories in matters related to and dependent upon the physical components of our coal beds have made necessary the adoption of a technique of megascopic description that can be readily understood and easily used by both the technician and the layman. This terminology of description has not been widely used in America, but its merits are such as to inspire hope for its general adoption. To the ends that standards of usage may be established as soon as possible, the present explanation of the application of the terms to Illinois coals is advanced. The explanation requires some consideration of the original definitions of the terms and of Continental usage. The Illinois State Geological Survey has endeavored to adhere closely to the denotations of the original definitions.

DURING the last ten years, the Illinois State Geological Survey has given considerable attention to the physical constitution of Illinois coals. The objectives of these investigations concern (1) the botanical constitution of coal, (2) the physical varieties of coal material, (3) the fundamental chemical constitution of the physical varieties of coal material, (4) the phenomena resulting from the application of pressure to coal under different conditions of time and temperature, (5) coal classification, (6) geological problems relating to the distribution, structure and

[1] Published by permission of the Chief, Illinois State Geological Survey. Presented before the Society of Economic Geologists, New York Meeting, February 16, 1939.

description of the coals, and (7) problems of the preparation and utilization of coal. This emphasis on the physical characteristics of Illinois coal has made essential the adoption of a convenient nomenclature of description useful in presenting the results of the investigations both to the layman and to the scientist.

Two principal schools of descriptive nomenclature of coal exist—the American and the British, that proposed by R. Thiessen[2] (1) and employed by the U. S. Bureau of Mines, and that proposed by Dr. M. C. Stopes (2) of England, both originating about 1919–1920. The Thiessen nomenclature is botanical and genetic and depends for application upon microscopic determinations. The Stopes' nomenclature, on the other hand, is called "petrographic" and is primarily megascopic and hence applicable to hand specimens or to the coal in the bed.

The British system of nomenclature, which has a much wider general use outside America than has the American system, has been the subject of much controversy among European coal technicians. Because of this and the ensuing redefinitions of terms, their meanings have become diverse from country to country, making it necessary for each laboratory to define the terms used. The Illinois State Geological Survey, having adopted the British nomenclature, occupies an unusual position in America in its acceptance of these names. However, it is our belief that the use of this nomenclature will expand in this country; if so desirability of uniformity in usage will not be questioned. To this end, the present explanation of the meaning of the terms used in the megascopic description of Illinois coals is presented.

MEGASCOPIC DESCRIPTION OF ILLINOIS COALS.

In any block of common banded Illinois bituminous coal, ordinary visual inspection reveals three or four varieties of coal material, each having individual and identifying characteristics (Pl. I, Fig. 1). The differences among these megascopic com-

[2] Numbers in parenthesis refer to the bibliography at the end.

FIG. 1. Herrin (No. 6) coal, Orient No. 2 Mine, Chicago, Wilmington and Franklin Coal Co., W. Frankfort, Ill., showing Fusain (F), Vitrain (V), and Clarain (C) bands.

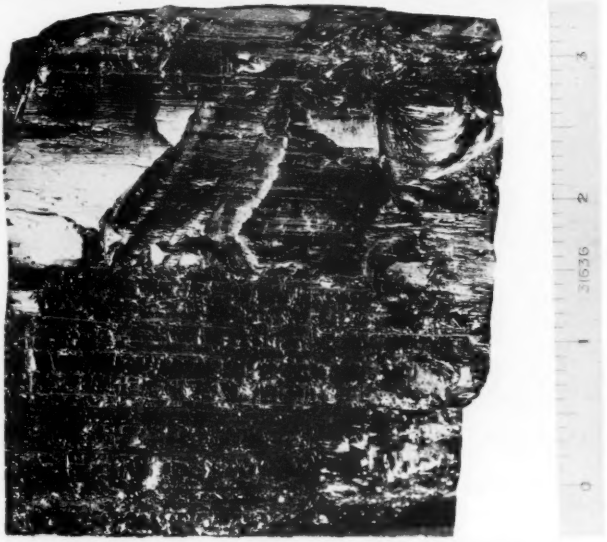

FIG. 2. Top bench coal of Herrin (No. 6) bed, Darmstadt Coal Co., Lenzburg, Washington Co., Ill., composed largely of Clarain; that in upper half is bright and dense with minor micro-Vitrain of microscopic thickness; lower half contains more micro-Vitrain. cf. Fig. 1, 5.

ponents are more or less apparent on any broken surface that crosses them, but they are generally particularly noticeable on freshly broken surfaces such as joint plane or cleat surfaces crossing the bedding more or less at right angles. These components are believed to be the coal " ingredients " of Stopes (2) designated by the names fusain, vitrain, clarain, and durain.

Fusain in Illinois Coals.

Fusain, or mineral charcoal, is most readily discovered on bedding surfaces of Illinois coal (Fig. 4). Not uncommonly,

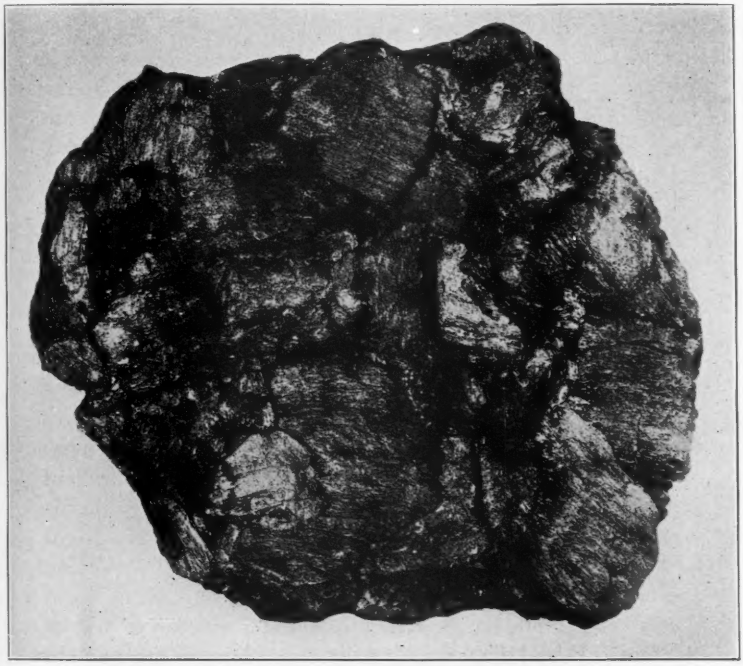

FIG. 4. A lump of fusain from Herrin (No. 6) coal bed in the mine of the Pyramid Coal Corporation, Pinckneyville, Perry County, Ill.

such surfaces are completely covered with fusain, the coal bed evidently having separated at the position of a thin bed or lens of the material.

Fusain not impregnated with mineral matter is very friable and is the chief component in the finest coal dust. On the other hand, the great porosity of fusain makes it particularly susceptible to mineral deposition, so that it is commonly impregnated with calcite, pyrite, or more rarely kaolinite. Such fusain is hard, but otherwise no different from the soft unmineralized fusain.

In general, fusain offers no particular problem in identification or nomenclature in hand specimens of coal. In certain instances, however, fusain can be seen to grade laterally into vitrain. The intermediate material, which is neither pure fusain nor typical vitrain, has been designated *Halbfusit* (3) (half-fusain or semi-fusain) by certain German writers. Jongmans and Koopmans (4) have named such material fuso-vitrain, fuso-telain, vitro-fusain, or telo-fusain depending upon the proportion of fusain and structureless vitrain and vitrain showing structure (telain) that may be present. These, however, are distinctions based upon microscopic determination. Semifusain is a satisfactory megascopic anglicized name for such transitional material, which, however, is not commonly recognised with the unaided eye.

Vitrain in Illinois Coal.

Banded Vitrain.—A smooth, freshly broken joint or cleat face of a lump of Illinois coal usually displays, in addition to more or less fusain, a succession of thin strips or bands of brilliant glassy looking, jet-like coal, alternating with strips of, or bands of, coal usually broader and having a luster varying from bright to dull (Fig. 5). Even the brightest of the intervening layers does not equal the jet-like coal in brilliance. This jet-like coal is believed to represent the vitrain of the British coals as named by Stopes (2) and the jet of black lignites. Bands of vitrain are a common feature of Illinois coals and represent the cross section of lenses of the material. It is the presence of these lenses of

vitrain that produces the banded appearance or structure of the normal banded bituminous coals such as are most commonly found in Illinois. The horizontal aspect of the material (Figs. 6 and 7) is characterized by a glassy conchoidal fracture so that no horizontal plane surfaces exist.

There is no absolute measure of the brilliance or luster of vitrain, which increases with the rank of the coal. Similarly,

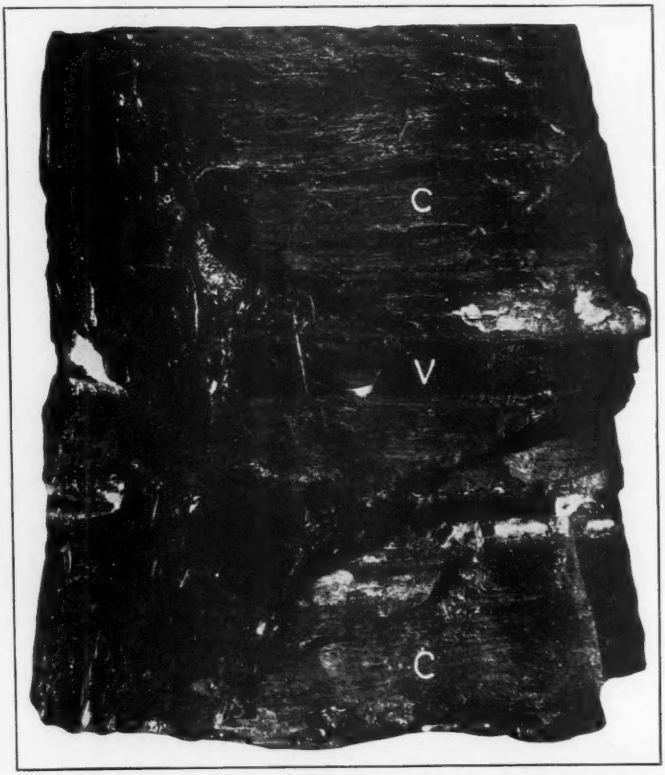

FIG. 5. Coal from Herrin (No. 6) bed in the mine of Valier Coal Co., Valier, Franklin Co., Ill., showing a band of vitrain (*V*) between two thick bands of clarain (*C*).

the brittleness of vitrain increases with its rank. But even in the relatively low-rank, high-volatile coals such as are found in Illinois, the vitrain is much more brittle than other ingredients of the coal bed, so that a disproportionate amount will segregate

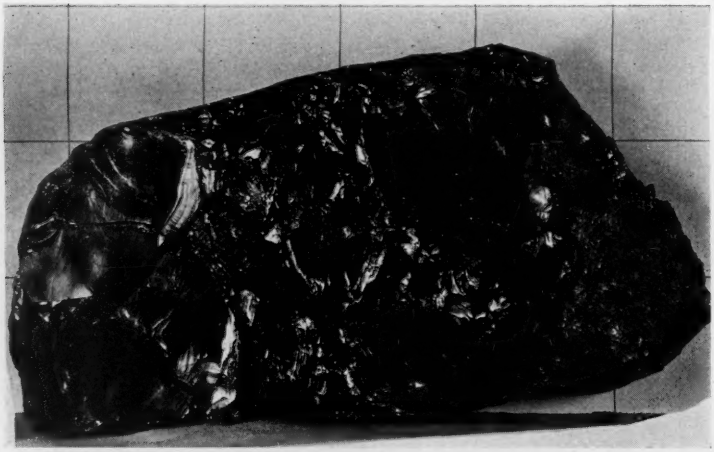

FIG. 6. Horizontal broken surface of a band of vitrain in coal from Herrin (No. 6) bed in the mine of the Midland Electric Coal Co., near Farmington, Fulton Co., Ill., illustrating the conchoidal fracture. (Net is 2 inches square.)

in fine sizes other than the fine dust. It may be observed that the brittleness of the vitrain is of a different kind of breakage than the friability of the fusain. The latter when handled will leave the fingers covered with splintery dust; the former is clean to handle.

The Use of the Term Vitrain.

The use of the term vitrain as a name for a variety of coal requires some consideration in view of the lack of agreement among coal technicians and writers concerning the meaning and application of the term.

Vitrain as Defined by Stopes.—In 1919, Dr. M. C. Stopes (2) added the names vitrain, clarain, and durain to the nomenclature of coal description, these materials, with fusain, being the

FIG. 7. Horizontal fracture surface of a band of vitrain in coal from one of the Brazil Block beds in Clay Co., Ind., illustrating the character of the fracture and the characteristic kaolinite-filled shrinkage cracks.

" four distinctive and visibly differing portions forming the mass of an ordinary bituminous coal," which can be recognized and separated from each other " macroscopically by hand and microscopically in thin sections." In the introductory classification,

vitrain is defined as having "conchoidal fracture, brilliant in appearance." In an explanatory paragraph, she says:

> The fourth ingredient, the vitrain or brilliant bands, have been less considered in the past, but are, as a matter of fact, particularly interesting. These brilliant bands in a favorable sample are definitely delimited from the rest of the coal, much more so than either the ordinary bright clarain or the dull durain from each other, which, owing to the finely lamellar nature of the coal in which they are interlarded, are sometimes hard to separate. The true vitrain, however, generally forms a very definite and often sharply straight-cut band, varying from 2 to 6–8 mm. thick. There are, of course, brilliant streaks of smaller size down to almost hair-like flecks. The larger, however, are the more typical vitrain zones.

Her description of vitrain is further amplified on page 475 of the same article as follows:

> *Vitrain* occurs as definite rather narrow bands, in some instances straighter and flatter than other bands of coal, and in some instances more obviously lenticular. True brilliant vitrain bands are often markedly uniform in thickness for considerable distances, and are commonly about 2 mm. to 3 to 4 up to 6–8 mm. thick. The limiting layer between the vitrain and the contiguous clarain and durain is generally sharply marked and is often a clean-cut definite surface (Plate 11, fig. 3). A single brilliant band does not exhibit the fine banding detectable even in the brightest clarain, but is a coherent and uniform whole, brilliantly glossy, indeed vitreous, in its texture.

Certain statements by Stopes relative to the microscopic characteristics of vitrain are now quoted because they contain those remarks that seem to have confused the application of her megascopic terminology (2, p. 481):

> *Vitrain* is, in my experience, unobtainable in *large* sections, as true vitrain occurs almost entirely in thin bands, which tend to break into small segments. In section when pure, its essential characters are its translucency (in which it resembles clarain) and its structureless and uniform texture in which it differs from all other parts of the coal . . . if the purest, most brilliant vitrain is selected, it is essentially homogeneous. . . . There is, consequently, in *pure* vitrain no banding or differentiation of parts in relation to the bedding plane of the deposit, though any individual mass of vitrain generally itself forms a horizontally extended band, lying parallel to the bedding of the coal.

The descriptions of megascopic characteristics of vitrain presented by Stopes in 1919, and the qualifications with respect to the microscopic structure in the last sentence quoted, namely "that there is no banding or differentiation of parts *in relation to the bedding plane of the deposit*" justify the application of

the name vitrain to all bands of jet-like coal found in Illinois coal beds even had there not been the later elucidation of the meaning of the term by Stopes in 1935, (5) as will be explained below. The vitrain of the Illinois coal beds possesses all the

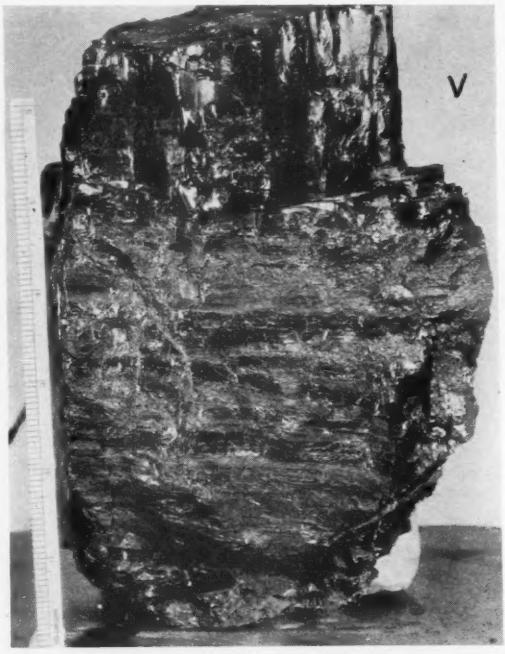

FIG. 8. Coal from Herrin (No. 6) bed in St. Ellen mine of Perry Coal Co., St. Clair Co., Ill., showing a band of vitrain 2 inches (40 mm.) in width.

characteristics assigned to the megascopic appearance of the vitrain of British coals, although the vitrain may occur in bands as much as 2 inches (40 mm.) in thickness (Fig. 8) and be somewhat less brilliant than the vitrain of the British coal beds. The differences in both instances may be due to the fact that Illinois

coals are of somewhat lower rank and hence less compressed than the British coals.

It must be pointed out, moreover, that microscopic criteria are not requisite for megascopic identification and classification. If certain forms of vitrain display plant structure, whereas other vitrain is thought not to do so, subdivision on the basis of such distinction may be possible for the purpose of microscopic classification, but the subdivision should be within the general variety of coal named vitrain on the basis of megascopic criteria.

Vitrain and Anthraxylon.—Stopes' comments on the microscopic characteristics of megascopically differentiated vitrain, and the observations of other investigators on material of this kind, have resulted in the question of the microscopic characteristics becoming controversial, which has hindered the general adoption of the term even for megascopic description. Of special interest to American coal technologists is the use of anthraxylon as a synonym for vitrain.

Thiessen in 1920 (1), after defining "bright coal" as one having "jet-black pitchy appearance, more compact (than dull or matte coal) and breaking with conchoidal fracture," states that:

> *Bright coal is anthraxylon.*—It is not difficult to show that the so-called "bright coal" are components that are derived from the woody parts of plants, parts that at one time were largely composed of wood. Thin sections were cut, both cross-wise and parallel to the bedding planes, from a considerable number of different beds and were examined with a view of determining their origin. Every one examined proved to be derived from some woody plant tissue either of stem, branch, or roots. In every one the cell structure was well enough preserved so as to leave no doubt as to its origin. "Bright coal" has yet to be found in which no trace of cell structure is observable.

In later contributions, Thiessen continued to use the name anthraxylon for coal material referred to in the preceding quotation as "bright coal." Thus, in 1937 he says (6): "Let us first turn to the larger or thicker bands, the strands or bands generally called vitrain, chiefly by Europeans, and anthraxylon by us"; thereby indicating his continued adherence to the belief that the material megascopically identified as vitrain is coalified

woody material and always displays microscopic evidence of its origin.

The identification of anthraxylon is based entirely on microscopic criteria. The declaration that all vitrain is anthraxylon makes unnecessary the use of the longer word at least for bituminous coals. Preference for the shorter name also rests upon the possibility that application of microscopic technique to megascopically identified vitrain may discover the existence of both anthraxylous and non-anthraxylous vitrain.

In 1935, Stopes revised her classification of the petrographic components of coal (5) and defined the megascopic appearance of vitrain in the following summary:

> Thin horizontal bands visible to the naked eye up to 20 mm. thick, though may be in thicker lenticles. Brilliant gloss, strong rectangular fracture perpendicular to the bedding, conchoidal fracture in other directions. Clean specular reflection. Very friable in small cubes with curved sides; quite clean to the touch. Not intrinsically stratified parallel to the bedding plane, but may show striations due to plant structure irrespective of bedding plane.

This modified definition of vitrain, which permits the inclusion of coal that actually shows plant structure arranged irrespective of the bedding plane, dissipates the value of claims such as that of Seyler (7) in 1931 who says, "since Stopes has stated that no coal band which contains recognizable plant structure can justifiably be called vitrain, we must adhere to that definition."

Structureless Vitrain.—Although the identification of coal as vitrain is not dependent upon its possession or lack of possession of plant structure, a considerable group of continental coal technicians and authors have made an issue of this particular criterion as a basis for the identification of vitrain. Working mainly with polished or polished and etched surfaces of coal, and claiming that considerable portions of the brilliant jet-black coal lacks traces of plant structure, this group has proposed and used the name telain (3, 8) (anglicized from Telit) as the name of coal having the general megascopic characteristics of vitrain but exhibiting microscopic traces of plant tissues (Fig. 9), the term vitrain (Vitrit) being restricted to material showing no

structure.[8] Not only is vitrain required by this definition to be without structure, but it constitutes a penetrating substance and binding agent. These definitions make it impossible to identify either vitrain or telain megascopically.

FIG. 9. A portion of a thin section of a block of Herrin (No. 6) coal from a mine at Winkle, Perry Co., Ill. The upper two thirds represents part of a vitrain band of which the lower half shows definite cell structure and the upper half is apparently structureless at the magnification used (200 ×). The bottom part represents clarain.

Microscopic Subdivision of Vitrain.—In 1935 (5) Stopes proposed a subdivision of vitrain on the basis of microscopic criteria primarily in recognition of the fact that certain vitrain bands show traces of plant tissues. The division of vitrain into structureless Eu-vitrain and Pro-vitrain that shows structure is,

[8] Vitrit: (3) Ganz structurlose Grundmasse, von welche die Kohle durchzogen ist and die als Bindmittel dient.

Telit: Grösser Gewebefragmente welche ganz von Vitrit durchzogen sind und deren Zellraume ganz damit ausgefullt sind.

however, based entirely upon microscopic criteria and is impossible of application in megascopic classification.

Clarain.

Megascopic identification.—Within the general group of bright coals all bands, lenses, or benches of coal that are bright, but are not classified as vitrain or fusain, are clarain (Pl. I, Fig. 2). The brightness of clarain is one of its identifying characteristics; the silkiness of its luster is another. One searches vainly in Stopes' original description (2) of the banded ingredients for a precise description of the megascopic characteristics of clarain. She describes it definitely as "bright" (2, p. 272) and differentiates it from vitrain by the brilliance and conchoidal fracture of the vitrain and the "streakiness" (2, p. 274) of the clarain. The description of the luster as silky is believed to be a more precise denotation of the appearance than the term streaky. Both streakiness and the sub-laminations producing silkiness of luster arise from the parallelism of the particles of the coal material. This silkiness of luster is distinctly different from the smooth brilliant luster of a band of vitrain in the same coal.

It should be understood that comparison of brilliance of luster of different ingredients should be made between vitrain and clarain in the same coal and not between heterogeneous vitrains and clarains. The difference is a relative one only, the relation being one that exists in the same coal bed or in the same block of coal after removal from the bed. The relative brightness of vitrain and clarain in the same coal is likely to depend upon the amount of fine or micro-vitrain present in the clarain. At any rate a clarain composed of a large proportion of such micro-vitrain will be bright. On the other hand, even without megascopic evidence of the presence of vitrain, clarain is bright. The explanation in microscopic terminology is that clarain is composed of a predominating proportion of translucent material, whether this material consists of anthraxylon or of attritus. This is a fundamental cause of their megascopic appearance, but is of course not discoverable megascopically.

Stopes' brief description of the physical characteristics of clarain states (2, p. 474) that

> Clarain occurs generally in bands of variable thickness, and when seen in a face at right angles to the bedding plane, they appear parallel to it. Like durain, they are ultimately widely extended lenticular masses. Clarain, even where streaked with durain, has a definite and smooth surface when broken at right angles to the bedding plane, and these faces have a pronounced gloss or shine. This surface luster is seen to be inherently banded, as well as to have bands of durain intercalated between its own bands.

The reference of all Illinois coals with silky luster to clarain does not appear to be contrary to the significance of the original description of this ingredient by Stopes.

Durain.

Megascopic Identification.—Durain is dull coal characterized by lack of luster, matte or earthy appearance and black to lead-gray color (Fig. 10). It is characterized by notably greater hardness than is possessed by the other ingredients. All durain is dull, hence its appearance in this respect is similar in all coal beds. However, since the degree of brightness of clarain and of vitrain varies from coal to coal, particularly with the rank of the coal and the amount of exposure it has suffered, there is no absolute measure of contrast between bright and dull coals. In general, the contrast is greater the higher the rank of the coal, that is, within the bituminous classes. Whether a dull coal appears black or grayish is unimportant in the identification of the coal as durain. Two persons will rarely agree as to the amount of grayness present. The contrast between the brilliant black of vitrain and the dull black of durain is commonly such as to give the impression of grayness to the duller coal, when the two ingredients are in relatively close association.

Stopes' description of the megascopic appearance of durain is as follows (2, p. 474):

> Durain is hard, with a close firm texture, which appears rather granular even to the naked eye. However straight the break across it, the broken face is never truly smooth, but, if looked at closely, always has a finely lumpy or matte surface. Generally, even in the dullest of durain bands, a few (or many) flecks or hair-like streaks of bright coal are to be seen.

FIG. 3. Typical cannel coal from Lackey, Kentucky, Elkhorn Coal Bed.

It
clara
Meg
are c

Fig
the
Fran
band

Th
parti
vitra
shre
of S
clara
ment

It needs to be emphasized that the original descriptions of clarain and durain definitely differentiated between the two. Megascopically distinguishable thin bands of durain in clarain are definitely mentioned (2, p. 475).

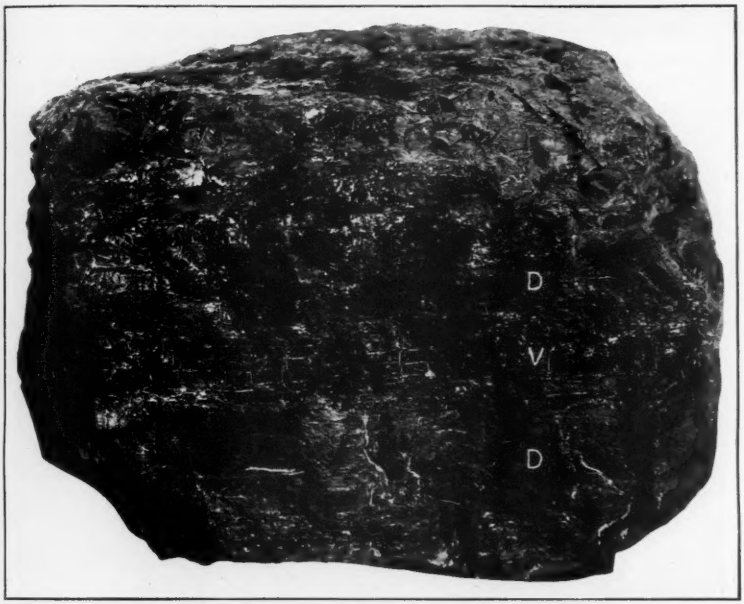

FIG. 10. Coal from Herrin (No. 6) bed in the Orient No. 2 mine of the Chicago, Wilmington and Franklin Coal Co., West Frankfort, Franklin Co., Ill., consisting largely of durain (*D*), but with four narrow bands of vitrain (*V*) in the middle of the block.

This position is opposed to that of certain European authors, particularly E. Stach (11), who holds that clarain is a mixture of vitrain and durain, the vitrain in clarain being distributed as fine shreds in a ground mass of durain. The so-called Humodurit of Stach (11, p. 149) is regarded by him as synonymous with clarain and is translucent throughout except for occasional fragments of fusain.

Opacity of Durain.

Just as the sheen characteristic of clarain is believed to be definitely related to and the result of the translucency of its constituents, as observed in thin sections, so the dullness of durain results from the predominant opacity (Fig. 11) of its components. Although Stopes did not definitely list opacity as one of the criteria for the identification of durain, since this could not be

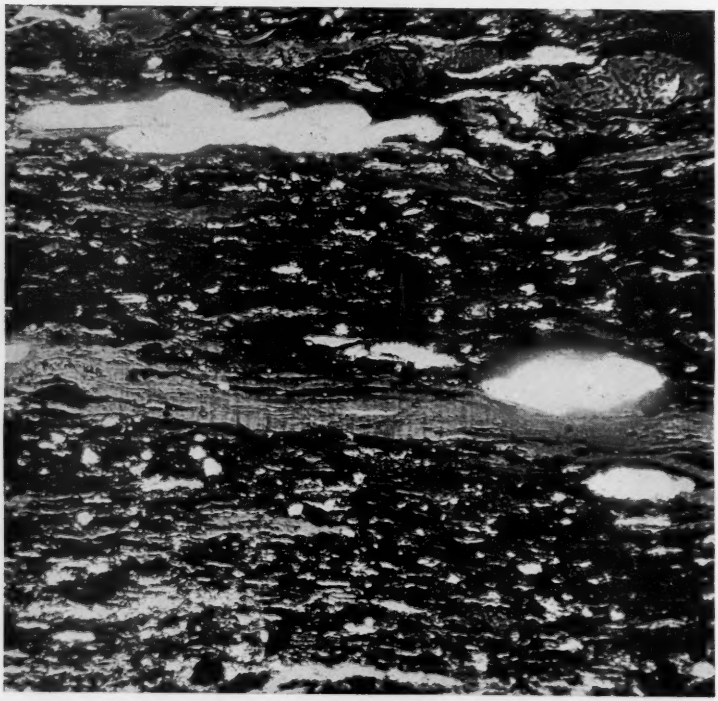

FIG. 11. A portion of a thin section of a block of Herrin (No. 6) coal in the mine of the Clarkson Coal and Mining Co., Nashville, Washington Co., Ill., illustrating the opacity of the groundmass of durain. The section is sufficiently translucent so that the coal represents semi-splint rather than true splint or durain.

determined without the microscope, she observes that material classified megascopically as durain when viewed microscopically is found to be composed predominantly of opaque material in which the majority of the " roundish or polyhedral fragments " of which it is composed are blackish or opaque. She further says (2, p. 479):

> The granules are closely packed and form a coherent mass, but mixed with them are the most characteristic spore exines. These may be whole or in fragments. The microspores are most conspicuous, and their very thick exines are clear and brilliantly colored, almost red, though when thinner they are reddish gold to pale gold or amber colored.

With the effect of making more definite the contrast between durain and clarain, she says:

> Throughout the texture of the less pure, streaked durain are seen in section small, clear, generally lenticular bands or flecks of more golden color. These are the streaks of clarain which so commonly lie embedded with the durain. . . . One may say that, on the whole, durain is essentially composed of a high proportion of opaque, fine, granules with many macro- and microspore exines scattered through it like currants in a pre-war pudding.

Attritus.

Thiessen referred to all material that he does not identify as anthraxylon and fusain as attritus. Vitrain and fusain in general represent coalified tissues that are, and the only ones that are, naturally preserved in large units, whereas the attritus represents all of the other parts of the plants as well as degradation products, which are naturally preserved in small units.

Opaque and Translucent Attritus.—Attritus is classified by Thiessen as translucent and opaque. The attritus of clarain is predominantly translucent. Clarain is composed of more or less translucent attritus and thin shreds of anthraxylon. The shreds of anthraxylon may be recognized, however, only by the microscope, so that the differentiation of anthraxylon and attritus is impossible megascopically. The fact that the coal is composed of translucent material gives it the silky luster diagnostic of clarain.

Durain consists predominantly of opaque attritus. This is equivalent to saying that pure durain is the same as the coal known in America as splint coal. In general, Illinois dull coals contain

enough translucent attritus to modify materially their character from that of true splints, and generally are more correctly designated semi-splints. However, since the fact of opacity cannot be determined megascopically, all dull coals are grouped together as durain.

Cannel Coal.

Cannel coal constitutes a special variety of coal not included by Stopes among the common varieties of coal occurring as banded ingredients of British bituminous coal beds. Thiessen treats it as essentially non-banded coal. In coal beds found in Illinois, bands and benches of coal having characteristics more or less resembling those of cannel coal are not unknown, and they may contribute to the banded appearance of the coal beds. The identification of cannel coal is at the present a matter of megascopic determination. The criteria for identification consist of its black color, greasy to sub-greasy luster (Plate II, Fig. 3), evenness and extreme fineness of grain, absence of or poorly developed horizontal laminations, and conchoidal fracture on a fairly large scale. The coal is relatively brittle.

Cannel, like durain and clarain, is an attrital coal. Microscopic examination shows that some cannels contain much opaque matter and others (probably less common) contain relatively little. Undoubtedly there will be some difficulty in identifying certain coals that are transitional between cannel coal and durain. As long as the criteria for the microscopic differentiation of cannel coal is more or less indefinite, exact megascopic identification can scarcely be expected. In general, only those bands or benches of coal possessing the common megascopic characteristics listed above should be identified as cannel coal.

Elimination of the Term Clarain.—Certain groups of European technologists, particularly represented by E. Stach (11) and Jongmans (4), who adhere to the technique that employs polished or polished and etched surfaces for the study of coal have discarded the name clarain from their descriptive vocabulary, believing that clarain is only a mixed variety of coal composed of durain and more or less vitrain in units of small dimension. The difference

between translucent and opaque material is not regarded by them as of sufficient fundamental importance to justify the differentiation of clarain as a variety of coal coordinate with vitrain and durain. The present writer and his colleagues believe that the original British system of nomenclature is more useful.

SUMMARY AND CONCLUSIONS.

Illinois coal as seen in the bed, the lump, or the hand specimen is composed of the same four varieties or ingredients of coal recognized by Stopes in British bituminous coal beds, namely vitrain, clarain, durain, and fusain. In addition, bands or benches of cannel or canneloid coal are also found in Illinois coal beds. The term fusain enjoys general usage. Vitrain is the relatively brilliant coal in a bed that largely imparts the banded structure to banded bituminous coals. It corresponds to the thicker strands of anthraxylon as identified by Thiessen. Clarain is relatively bright coal with a silky luster. It is composed more or less of fine strands of anthraxylon and of translucent attritus. The translucency of the material in thin section is characteristic. Durain is coal with a predominant matte or dull texture, and black to lead gray in color. The general opaqueness of this coal in thin section is characteristic. It is composed largely of opaque attritus. Cannel coal, like clarain and durain, is predominantly an attrital coal. It is black, but tends to have a greasy luster, an exceedingly fine texture, and a conchoidal fracture. In thin sections some cannels are largely translucent but probably more cannels are largely opaque.

In establishing a system of megascopic nomenclature for Illinois coals, a simple but fundamentally accurate method is provided for field description and for the occasional hand specimen that reaches the laboratory. The facts provided by such a megascopic description will provide a basis for the megascopic classification of the coals found in Illinois and neighboring states in the Eastern Interior Coal Basin. Such description will make intelligent comparison possible and will provide a means of estimating from the description the probable susceptibility of a coal to

various preparation procedures and its adaptability to many varieties of utilization.

BIBLIOGRAPHY.

1. Thiessen, R.: Compilation and composition of bituminous coals. Jour. of Geol. 28: 185–209, 1920.
2. Stopes, Marie C.: On the four visible ingredients in banded bituminous coal. Studies in the composition of coal. Proc. Royal Soc. Lond., Ser. B, 90: 470–487, 1919.
3. Kühlwein, F. L., Hoffman, E., and Krüpe, E.: Durchfuhrung und praktische Bedeutung planmässig Kohlenpetrographischer Flozprofiluntersuchungen. Glückauf, 70: 1–28, 32–41, 1934.
4. Jongmans, W. J., and Koopmans, R. G.: Kohlenpetrographische Nomenklatur Jaarverslag, 1933: 49–63; Geol. Bur. Nederland. Mungebied Heerlen, 1934.
5. Stopes, M. C.: On the petrology of banded bituminous coals. Fuel, 14 (1): 4–13, 1935.
6. Thiessen, R.: What is coal? Appalachian Coals: (Mimeographed) 38 pp., and illus., Jan. 11, 1937.
7. Seyler, C. A.: Petrography and classification of coal: Proc. Soc. S. W. Inst. Eng., 47, 3, (2): 547–555, 1932.
8. Roos, Gerritt: Comparative researches on the variation of the constituents of coal of one seam from South Limburg (the Netherlands). Deux. Cong. L'Avancement Des Etudes de Stratigraphie Carbonifere, 1935, C. R. II: 1056–1161, 1937.
9. Thiessen, R.: Splint coal: A. I. M. E. Coal Div. Trans. 88: 644–671.
10. Wandless, A. M., and Macrae, J. C.: The banded constituents of coal. Fuel 8 (1): 4–15, 1934.
11. Stach, E.: Lehrbuch der Kohlenpetrographie. Berlin, 1935.

ILLINOIS GEOLOGICAL SURVEY,
URBANA, ILL.,
March 20, 1939.

THE GEOLOGY OF THE CANADIAN MALARTIC GOLD MINE, N. QUEBEC.[1]

D. R. DERRY.

ABSTRACT.

The geology of the Canadian Malartic Gold Mine, Northern Quebec, shows the following features of especial interest:

(1) An interesting combination of structural features affecting the position and shape of the ore bodies, (2) the presence within the area of the mine of two entirely different types of auriferous ore bodies, (3) the fact that the second of these, forming so far only a minor portion of the total ore, consists of material resembling pegmatite in appearance and composition.

The main ore bodies, in graywacke, show a composite structural control. The application of stresses after the major folding resulted in the formation of a steep-pitching drag-fold which partially controlled the shape and position of contemporaneous porphyry intrusion. Continued application of the same stresses caused fracturing which was concentrated in an E–W and a NW–SE zone of brecciation. Silicification, other alteration and the formation of ore bodies in these zones followed.

The "pegmatitic" type of ore occurs only within un-silicified porphyry and consists of quartz, feldspar, biotite and a variety of other minerals, filling several sets of fractures. These fractures appear to be associated with slip-planes along wide chloritic seams cutting through the porphyry stock. The structural and chronological relationship of this type of ore with the main graywacke ore is discussed.

CONTENTS.

Introduction 496
General Geology 496
Mine Geology 497
Structure
  Folding 506
  Fracturing 507
Ore Bodies
  Ore in the Graywacke 513
  Ore in the Porphyry 516
Genetic Relationship of "Pegmatite" and Gold 520
Time Relationships of the Two Types of Ore 521
Acknowledgments 523

[1] Presented before the Society of Economic Geologists, New York Meeting, February 14, 1939.

INTRODUCTION.

THE gold mine known as the Canadian Malartic is in Fourniere township, Quebec, about forty miles east of Noranda. The mill currently treats about 700 tons of ore per day, averaging approximately .145 ounces gold per ton. From a geological point of view the mine is of interest, firstly from the variety of structural features that have influenced the position and shape of the ore bodies, secondly because it has two completely different types of auriferous ore and thirdly because the second of these (by far the less important in tonnage) consists of veins of material closely related to pegmatite. The history, development and stoping methods of the mine are described in a recent paper by E. V. Neelands, General Manager, and J. P. Millenbach, General Superintendent.[2]

GENERAL GEOLOGY.

The geology of the area has been reported on by James and Mawdsley,[3] O'Neill,[4] and, more recently, by Gunning and Ambrose,[5] to whose careful work is due much of the successful development of the younger properties in the district. The part of the geological column for the district, as given in the latest report of Gunning and Ambrose is as follows:

Acid Intrusives—granite, porphyry, etc.
Cadillac Sediments—Graywacke, conglomerate.
Cadillac Belt—basic volcanics with tuff, agglomerate, etc., and basic intrusives.
Fourniere Sediments—Chiefly graywacke.

The mine itself lies in an area of graywacke sediments (referred to as the Fourniere sediments in the above column) gen-

[2] Neelands, E. V. and Millenbach, J. P.: Can. Min. & Met. Bull., 321, Jan. 1939.

[3] James, W. F. and Mawdsley, J. B.: Geol. Surv. Canada, Sum. Rept. 1925, pt. C: 52–77.

[4] O'Neill, J. J.: The Canadian Malartic gold mine, Abitibi County. Quebec Bur. Mines, Ann. Rept. 1934, part B.

[5] Gunning, H. C. and Ambrose, J. W.: Geol. Surv. Canada, Preliminary Geol. Map "Malartic Area, Abitibi County, Quebec," Paper 37–4, 1937.
Gunning, H. C.: Cadillac Area, Quebec. Geol. Surv. Canada, Mem. 206.

erally regarded as of Temiskamian age. A belt of basic lavas and some tuffs (the Cadillac belt) underlies the northern part of the property, the south contact passing about 1,100 feet north of the No. 1 shaft. The sediments and lavas have been intruded first by dikes of diorite and amphibolite, which strike about northwest and dip steeply northeast, and later by feldspar-, granite-, and alaskite-porphyries in stocks and dikes. The gold-bearing mineralization evidently followed closely the intrusion of the porphyries.

The Temiskamian rocks have been folded to form a major syncline, of which the axial plane runs between east and southeast. The Canadian Malartic and adjacent mines lie on the south limb of this syncline. The north limb of the Temiskamian series lies against the Keewatin lavas, and the south limb is partially cut off by a large granitic mass.

MINE GEOLOGY.

Temiskamian.—The only part of this system actually involved in the underground workings is the lower series of graywackes, a uniform succession of fairly well-bedded rocks with no marked horizons. Gradation of grain-size indicating that tops face north may be seen in several places on the surface and in diamond drill cores. Close to the ore-zones the bedding has been destroyed by brecciation and hydro-thermal alteration. The commonest alteration, developed mainly along the same zones as are followed by the ore, results in the graywacke being changed from the customary dark gray or black color, to yellowish brown, and from its usual gritty texture to a finer-grained, dense, hard material. This altered material is locally referred to as "silicified" graywacke, from its appearance and effect on drill steel. Microscopic examination, however, shows that silicification plays a comparatively minor role, confined mainly to fine stringers, and that the dense texture results more from the cementing of the brecciated fragments by dissolved and re-deposited feldspathic constituents of the graywacke, accompanied by some silica and a good deal of carbonate. The change in color seems to depend

largely on the removal of a proportion of the biotite, which is a very common mineral in the unaltered graywacke. This type of alteration is almost universally accompanied by pyrite mineralization with low, sub-commercial gold values. The more limited areas of the ore include much of this material which, however, shows no difference in appearance whether it carries .2 ounces or .02 ounces of gold per ton.

Basic Dikes.—Dikes of diorite and amphibolite that strike northwest and dip steeply northeast cut the graywackes. In the nearby East Malartic Mine, where the dikes cut soft talc schist, they are the more competent rocks and, in the ore zone, fracture

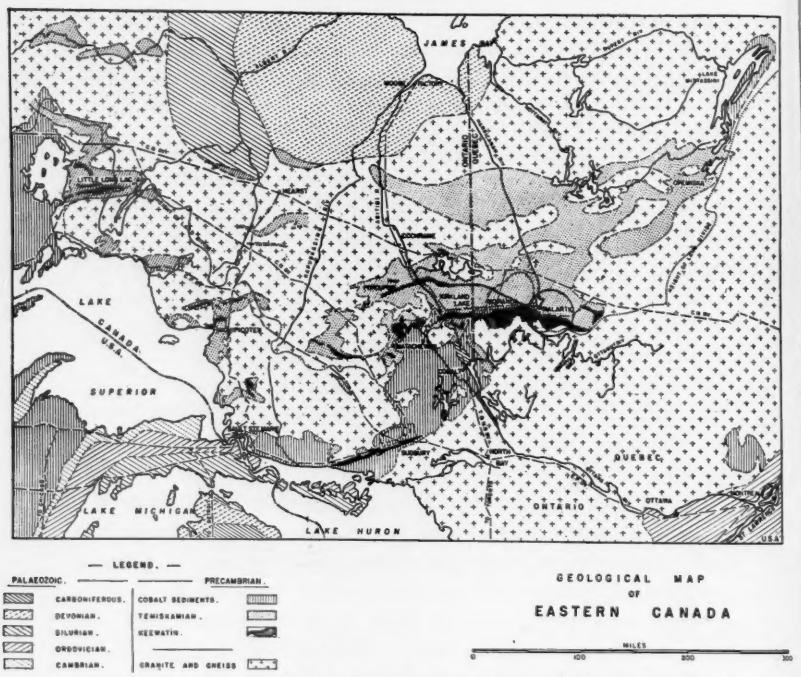

FIG. 1. Map of part of the Precambrian shield showing position of the Canadian Malartic Gold Mine. (Legends for Temiskamian and Keewatin should be reversed.)

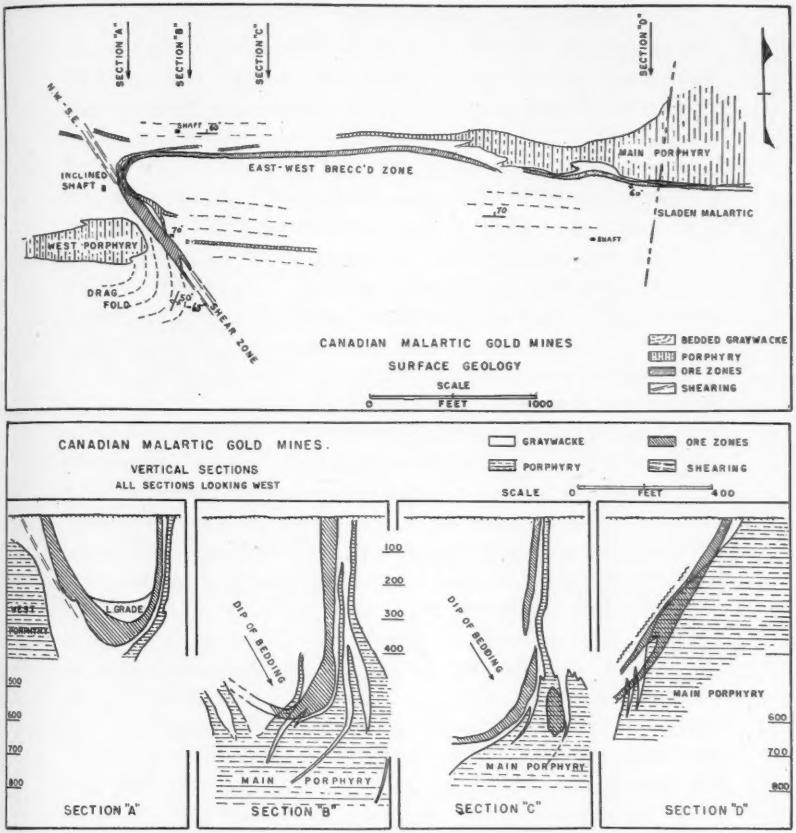

FIG. 2. Surface plan and sections, Canadian Malartic Gold Mine.

well and make the best grade of ore. In the Canadian Malartic mine the same dikes cut the harder graywacke and, being the less competent of the two, are sheared so that where they enter the ore zone they tend to pinch out and thus do not affect the grade of ore. Under the microscope these dikes are seen to consist of hornblende, biotite, chlorite and feldspar in variable proportions.

Acid Intrusives.—Within the area of the mine workings the commonest acid intrusive is gray to pink feldspar porphyry, of which two stocks, besides smaller dikes, outcrop on the surface. The larger of these occurs 2,000 feet east of No. 1 shaft (Fig. 2), straddling the Canadian Malartic-Sladen Malartic boundary. This lens-shaped mass pitches west, at least at its western end, irregularly at about 17 degrees, coming into the region of the No. 1 shaft at a depth of 600 feet below surface. The other stock of porphyry lies just southwest of No. 2 shaft in the "core" of an easterly-pitching drag-fold. The east nose of this stock pitches east about 65 degrees with the drag-fold. As a result, although on surface the two masses are quite separate, at the depth of the sixth level (750 ft.) they have come together to form one S-shaped mass, as shown in Fig. 3. It would appear that the porphyry as a whole was intruded with a westerly pitch, but that where it hit the drag-fold a "blister" of magma was injected up the axis of the fold. It may be mentioned here that in the Malartic district porphyries are commonly found to be associated and controlled in shape by S-shaped drag-folds. The origin of the drag-folds is discussed in a later section.

Thin sections of typical gray porphyry show it to consist, in the more massive phases, of closely packed phenocrysts of feldspar, with a relatively small amount of groundmass consisting of feldspar and biotite. The feldspar phenocrysts are about 66 per cent plagioclase, near albite, 26 per cent orthoclase and 8 per cent microcline, although the proportion varies a good deal. Thus, the rock is rather sodic monzonite in composition. The narrower dikes and tongues vary more, from dark gray rocks in which plagioclase phenocrysts lie in a fine-grained biotite-feldspar groundmass, to light colored dikes high in albite, probably at least in part secondary.

The original differences in composition are much obscured by hydrothermal alteration, which is of three main types. These are:

(1) *Silicification.*—This alteration is confined to zones mainly on the south side of the "main porphyry" and the eastern end

of the "west porphyry," which have been involved in the brecciation and shearing mentioned below. In the first stage of this alteration crypto-crystalline quartz, usually accompanied by fine-grained carbonate and some albite, follows cracks in the highly brecciated porphyry. In a later stage the silica and other replacing minerals have seeped through the rock as a whole, but the phenocrysts, though ragged, are still visible in the hand specimen. In the final stage the rock becomes a dense, light gray chert which would not be suspected to have anything to do with the original porphyry if it were not for the intervening stages. Silicification of the porphyry occurs in the same zones of brecciation as the alteration of the graywacke described above and the two processes were probably simultaneous, the porphyry, apparently having a greater attraction for silica than the graywacke. In places it is often difficult to define the original limits between the porphyry and the graywacke when highly altered. Experience has shown, however, that whereas the most highly silicified porphyry becomes a light gray or pale yellowish chert, the graywacke becomes a brown or olive color and slightly less cherty.

(2) "*Red Alteration.*"—This rather unsatisfactory term covers an alteration of the porphyry that results in the rock becoming red or pink in color and more highly feldspathic, at the expense of the ferro-magnesian minerals. It may effect part or whole of a dike or tongue, but is in other places confined to certain patches or zones. The resultant rock generally has a fresh appearance and might be taken for an original acid phase of the intrusive were it not for the relationship of this type of material to fractures and zones of movement. Before thin sections were examined it was thought that this alteration was an actual feldspar replacement. Microscopic examination, however, shows that the feldspar in the red material is identical with that in the normal gray porphyry (about 66 per cent albite and 33 per cent potash feldspar). The chief alteration seems to be the removal from the gray porphyry of biotite. The red color may be due to the precipitation of minute grains of ferric oxide along crystal boundaries and twin planes of the feldspar, the iron being derived from the dissolved biotite.

(3) *"Pegmatite."*—The word is purposely left in quotation marks because it is doubtful whether the rock should strictly come under this heading. Within the unsilicified areas of porphyry are certain patches, zones and veins of material which in appearance and mineral content certainly resemble pegmatite. The material does not occur in regular dikes with walls but is clearly a hydrothermal replacement and alteration of the normal porphyry, showing gradational or irregular contacts with it. The rock consists essentially of coarse, glassy quartz and red feldspar (mainly albite), with subordinate amounts of calcite, micas, tourmaline and other minerals. The important feature of the "pegmatite" from the economic point of view is that in many places it carries gold in commercial quantities. A fuller description of the mineral content and its relation to gold is given below under the heading "Ore in the Porphyry."

In mapping these occurrences one is struck by the resemblance and relationship between the "pegmatite" and the "red alteration" described above. It is often impossible to draw a sharp line between the two, especially where, as commonly occurs, the "red alteration" forms a border on each side of a vein of the pegmatitic material. The "pegmatite" differs only in containing quartz and other rarer minerals, and in being confined to certain fracture zones. It seems a logical conclusion, therefore, that the "pegmatite" represents a further stage of the process that started with the removal of biotite and production of the red coloration in the porphyry. This is further supported by the fact that in the actual veins of "pegmatite" red feldspar and the accessory minerals occupy the sides, merging into "red alteration," and quartz, the latest common mineral, fills the centres.

Chloritic Seams.—A curious feature of the wider part of the porphyry mass is the presence of what, at first sight, appear to be basic dikes, 1–5 feet wide, that traverse the stock in several directions. They consist of dark green, in places schistose, material consisting, as seen in thin section, of about 40 per cent cloudy feldspar and the remainder hornblende, chlorite, biotite and tourmaline. On most of these there has clearly been considerable

movement and in some cases this movement has resulted in complementary fractures breaking off into the porphyry. It is these fractures that contain most of the "pegmatite," but in a few cases this material is found replacing the chloritic seams themselves.

That these chloritic seams are not true dikes intruding the porphyry is suggested by the following evidence:

(1) They do not have chilled borders, even when unsheared.

(2) They are definitely cut by stringers of "pegmatite" and since the latter are thought to have been formed by solutions derived from the same magma as the porphyry stock, they must have been intruded, if they are dikes, between the consolidation of the main part of the magma and its end product—an unlikely event.

(3) In several places in the mine short tongues of the normal, gray porphyry appear to cut the chloritic material. In most cases, however, the contacts are slip-planes.

(4) Where traced out to the borders of the porphyry mass (by diamond drill holes) the material of the chloritic seams appears to grade off into graywacke. Moreover where part of a "dike" has escaped shearing the material strongly resembles re-crystallized graywacke.

However, thin sections made from several specimens from different seams show a good deal of variation in texture and composition and are inconclusive as to origin. All contain feldspar (apparently both plagioclase and orthoclase), some contain biotite as the main ferro-magnesian, but chlorite and hornblende are commoner.

From the above evidence it is thought by the writer that these wide chloritic seams are probably not basic dikes but are long, narrow inclusions of graywacke, between tongues or lobes of porphyry; and that these formed lines of weakness along which movement took place when outside stresses were applied just after the consolidation of the porphyry or during its late stages. It is suggested that this movement resulted not only in the recrystallization of the graywacke of the inclusions (probably with

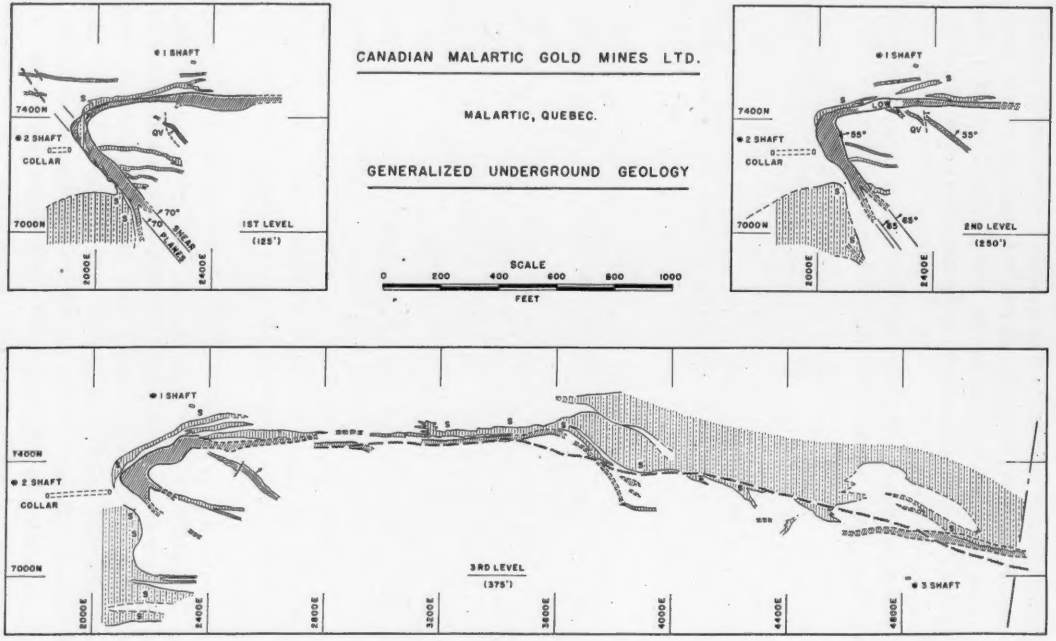
CANADIAN MALARTIC GOLD MINES LTD.
MALARTIC, QUEBEC.
GENERALIZED UNDERGROUND GEOLOGY
SCALE
0 200 400 600 800 1000
FEET
1 SHAFT
2 SHAFT
COLLAR
7400N
7000N
2000E
2400E
QV
70°
70° SHEAR PLANES
1ST LEVEL
(125')
55°
2ND LEVEL
(250')
3RD LEVEL
(375')
3 SHAFT
2800E
3200E
3600E
4000E
4400E
4800E

FIG. 3*a*.

1 SHAFT
PORPHYRY

FIG. 3a.

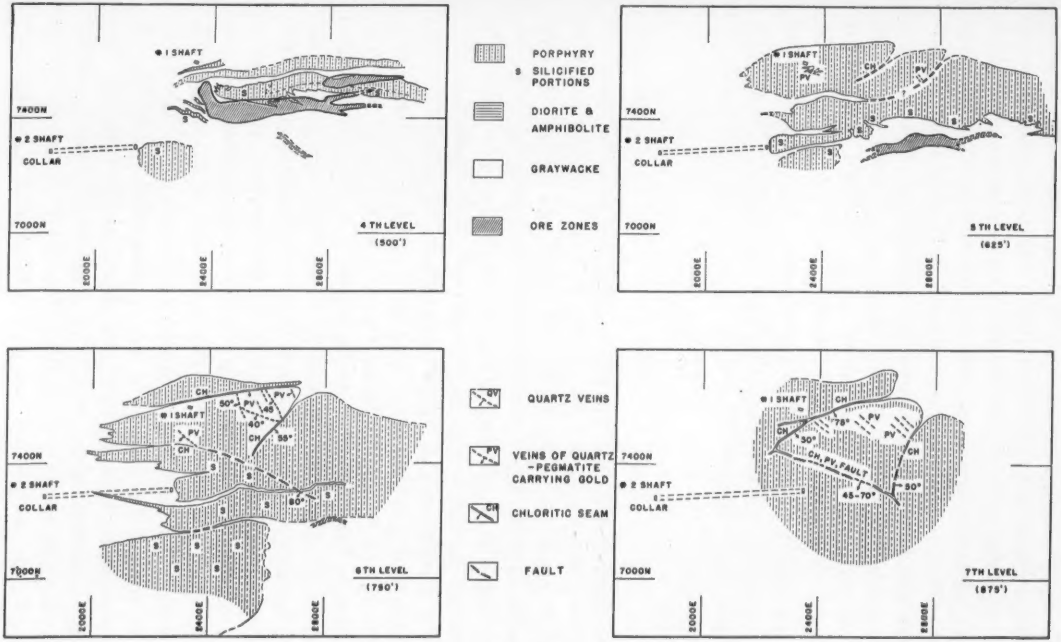

FIG. 3b.

FIGS. 3a AND 3b. Level plans showing general geology and ore bodies. Mine workings are omitted for clarity.

addition or removal of some of their constituents by porphyry end-product solutions) but in its being squeezed further into the mass of the porphyry along the planes of movement. Whatever their origin, the chloritic seams are important structural features and the bulk of the movement along them must have taken place before and during the deposition of "pegmatite."

It should be noted that the chloritic seams occur only in the unsilicified porphyry, never in the cherty, silicified material (in this particular mine). But within the silicified porphyry are long, narrow bands of silicified graywacke and it is suggested that these are the equivalents, in the silicified areas, of the chloritic seams in the fresh porphyry.

STRUCTURE.

Folding.

As mentioned above, the mine is believed to lie on the south limb of a major syncline, the prevailing strike being slightly south of east and the dip about 70 degrees north. In the region of the mine the strike is fairly uniform except for a drag-fold, which is important in controlling the shape of the porphyry and partially in localizing the ore. It is an "S-shaped" fold (southside-east) having a steep pitch of about 65 degrees to the east. From its position on the south limb of a syncline which, from the relative parallelism of the two limbs must have a nearly horizontal pitch, it is clearly impossible that this drag-fold is of the type produced by differential movement dependent on the major folding. In the mine workings the fold is obscured by later shearing, brecciation and alteration, but it is easily traced a few hundred feet south of the mine and southeast for half a mile or more along the trace of the axial plane. Similar folds are found to the west of the property and all would be produced by the beds to the south having moved east and slightly up with respect to the north side. It seems probable that such folds were produced after the beds were already upturned on the major folds, by forces similar to those that produced the big horizontal movements on faults in, for example, the Rouyn area. As far as the author is aware, there

is no standardized term to distinguish this type of drag-fold and the term " independent " drag-fold is suggested to differentiate it from the normal type dependent on differential movement towards the apices of major folds. Detailed mapping is showing up this " independent," steep-pitching type of drag-fold in an increasing number of cases in Precambrian areas, one of which was recently described by Flaherty at the Tashota Mine, Ontario.[6]

Fracturing.

A large number of faults, shears, slip-planes and tension fractures have been observed underground and on the surface. Only the more important of these are described below. The planes of movement within the main porphyry mass differ considerably from those outside it and the two groups are therefore discussed separately.

Planes of Movement Outside the Main Porphyry Mass.—(*a*) An east-west zone of brecciation, rather than shearing, having a vertical to south dip, forms the main locus for much of the ore in this mine and for almost all of it in the Sladen Malartic and East Malartic Mines to the east. In the Canadian Malartic no shear planes correspond to the direction of the zone as a whole, the movement resulting apparently only in brecciation. From the direction of dragging of porphyry tongues involved in the zone and other structures it appears that the south side has been moved east with respect to the north side. It appears that at least two movements have occurred on this zone, the first of which preceded and prepared the way for the silico-carbonatization and pyritization, whereas the second, which resulted in further, and probably slighter, brecciation allowed the entrance of auriferous solutions. The zone extends for a proved length of 9,000 feet east from the west end of the Canadian Malartic workings, but is barely discernible west of that point.

(*b*) Shear planes, with brecciation between them, striking northwest-southeast and dipping 75 to 55 northeast, are developed along the reversed limb of the drag-fold mentioned above, and

[6] Flaherty, G. F.: Can. Inst. of Min. and Met. Bull. 295, 1936.

these meet, and apparently cross, the east-west zone 300 feet west of No. 1 shaft (Fig. 2). They are the controlling influence on the south ore-body and also form the wide bulge at the west end of the ore on the east-west zone below the third level. So far as horizontal movement can be identified the west side has moved south with respect to the east side.

Probably in the same set as the above are numerous weaker slip-planes and a few actual faults, striking northwest and dipping 60 to 45 degrees northeast, throughout the whole mine but especially within the main east-west zone. From their close association and similarity of alteration and mineralization, the two systems (the east-west zone and the northwest-southeast fractures) appear to be contemporaneous. It is suggested that they are the two complementary shear directions resulting from a continuation of the same rotational stress that produced the drag-fold (Fig. 4).

(*c*) Near the junction of the east-west ore body with the northwest-southeast body a set of fractures cut across the angle so made, in a direction about N 30 to 60° E dipping about 55° E. The ore tends to follow the "short cut" made by these rather than extending to the actual junction of the two main zones. This direction is close to the theoretical direction of tension cracks that would be produced by movement on the two complementary shear directions described above. Although they have now none of the characteristics of true tension fractures, it is possible that movement later occurred on the fractures originally developed by tension. A gold-bearing cherty quartz vein cut in the unaltered graywacke in the angle made by the two main ore zones has approximately the same strike and dip.

(*d*) Slip planes striking slightly south of east and dipping steeply north occur abundantly underground throughout the mine and the area as a whole. They probably represent the regional flow cleavage and were developed before the other planes of movement described. They do not appear to have any influence on the ore.

(*e*) A set of fractures having a nearly north-south strike and

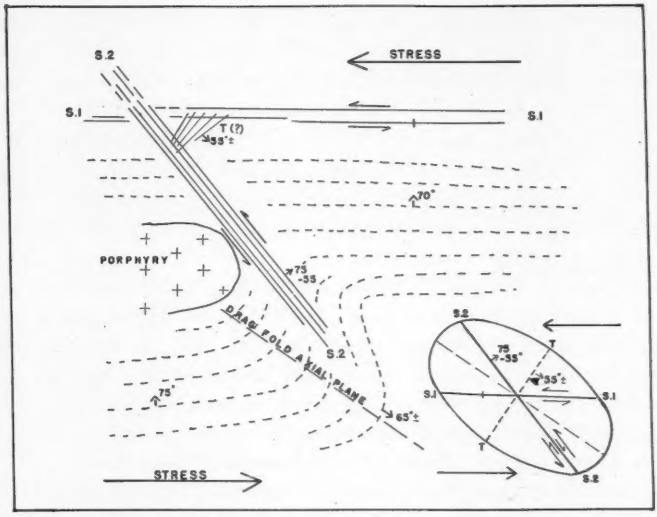

FIG. 4. Diagram showing application of the strain ellipsoid to the "independent" type of drag-fold and the two main fracture zones at Canadian Malartic Mine. Dotted lines—Strike of bedding; S1, E–W brecciated zone; S2, NW–SE shear zone. Movement on latter was probably east-side-south at first disruption but continued stress later resulted in a larger east-side-north movement on the same planes, as shown by field evidence. T, NE–SW fractures possibly originally tension cracks, corresponding to the tensional direction shown on the strain ellipse.

vertical dip (varying 15 degrees each way) is common throughout the mine, but especially within the zones of alteration and mineralization, through which they cut sharply. The majority of these planes are really joints with only fractional movement, but of rarer occurrence are faults with up to a few feet displacement, generally showing some brecciation. These fractures are certainly later than the brecciation and probably later than the ore solutions and although they are common within the ore zones are not found to show any consistent relation to high or low values.

(*f*) A single strong (in appearance) fault trends slightly south of east throughout most of the workings of Canadian Malartic

and of the adjoining Sladen Malartic Mine. The dip is in most places to the south between 70 and 45 degrees, but at its western end where the fault weakens, the dip becomes vertical and even steeply north in places. Although there is a considerable amount of gouge along this fault no very large movement has been proven. The fault approximately parallels the main east-west ore zone, lying either within the ore or in the hanging wall and appears to be a later expression of the same movement which formed this zone of brecciation.

Planes of Movement Confined to the Main Porphyry Mass.— As mentioned above, the main porphyry body, where opened up by mine workings between the 4th and 7th levels, is divided into several lobes or sections by chloritic seams up to four feet in width, resembling dikes. The most important structural and economic feature about these chloritic seams is that any post-porphyry movement tended to be deflected into these planes. The present work shows three different directions taken by this material but each tends to vary a good deal both along strike and dip. These are (Fig. 3*b* and Fig. 7):

(*a*) Strike slightly north of east, dip 60 to 80° S, represented by one seam near the north contact of the porphyry mass.

(*b*) Strike south 70–80 east, dip 50 to 80° S, represented by one seam about the middle of the porphyry mass. This one is apparently followed by the lower and western continuation of the late fault mentioned under (*f*) in the previous section.

(*c*) Strike about northeast, dip 45 to 55° SE, represented by two seams connecting the other two seams mentioned under (*a*) and (*b*). In Fig. 5 the veins lie in the angle between the seam mentioned under (*a*) and the more easterly of the two mentioned under (*c*).

Associated with these chloritic seams, especially the first two mentioned, are several sets of fractures entering the fresh porphyry itself and it is these which have been followed by the solutions that formed the "pegmatite," in many cases auriferous. The chief sets of fractures followed by "pegmatite" are as follows:

(*d*) Strike S 74 E, dip 35 to 45° S. There is only one good example of a single vein in this direction (602 E, Fig. 5) but this gives particularly good values in gold. A zone of tension fractures forming 605 stope (Fig. 5) has a trend S 50 E and dips 45° S and thus may belong to the same set.

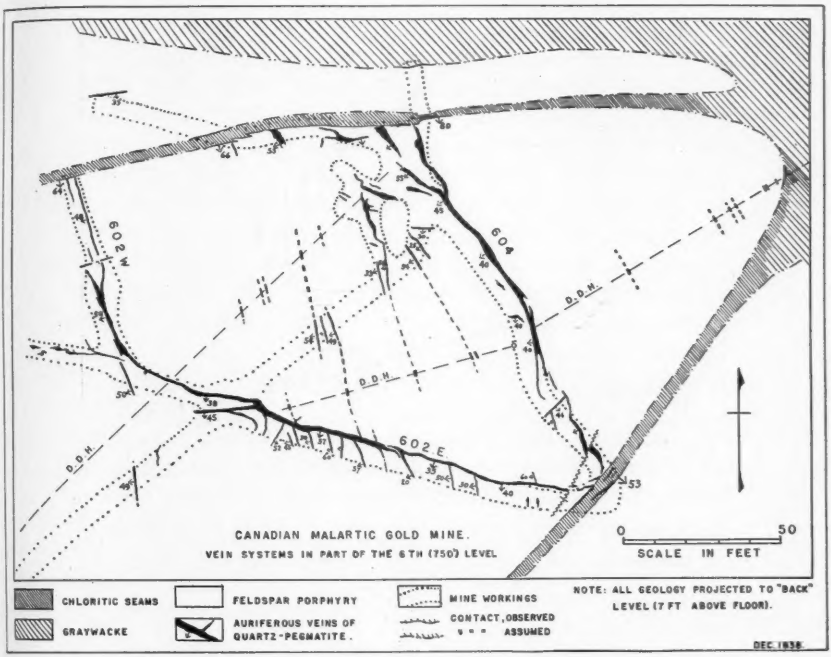

FIG. 5. Plan of part of 6th level, Canadian Malartic Mine, showing the relation of vein fractures in porphyry to "chloritic seams." Movement on the seams is apparently south side down and east on the northern one, and east side down and northeast on the southern one, most of the movement being earlier than the deposition of the vein-filling material.

(*e*) Strike N 10 to 30 W, dip 40 to 55° W. This set is well represented on the 6th level (Fig. 5) and is the commonest direction followed by the "pegmatite" so far as present work shows.

Both these and the previous set show slickensided surfaces and fairly regular widths and so are probably not tension fractures but complementary shear planes from two different movements on the chloritic seams.

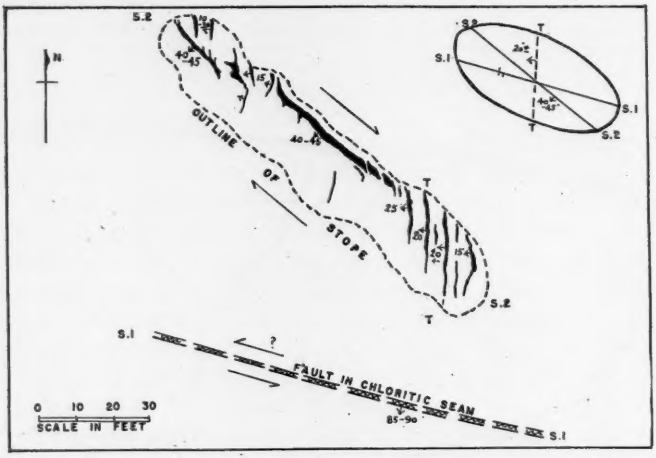

FIG. 6. Plan of the 605 stope, Canadian Malartic Mine, about fifty feet above the 6th level, showing relationship between fracture zone, individual tension fractures, and neighbouring "chloritic seam."

(*f*) Strike slightly east or west of north, dip 10 to 30° W. From their shape and arrangement in zones or breaking off main fractures, the pegmatite- and quartz-filled cracks of this set are clearly of the tension variety. They are well developed in 605 stope, as mentioned, and also break off 602 E vein (Fig. 5). Their attitude varies slightly according to the main fracture zone with which they are associated. Since they are rather close to set (*e*) in attitude the two are often hard to distinguish and a stringer may start on one and finish on the other. In the above fractures the "pegmatite" also occurs along the sheared chloritic seams, especially the most southerly (*b*).

That there is a close connection between the chloritic seams and the "pegmatite"-filled fractures is clear from their occur-

rence, but the detailed structural relationship of the two presents some difficulties. In the area in Fig. 5 are two chloritic seams and two sets of "pegmaite"-filled fractures (as well as some of the true tension fractures in many cases too small to indicate). If the chloritic seams are regarded as the two complementary sets of shear planes in a strain ellipsoid, then, apart from any other considerations, the vein fractures could not be tension cracks applicable to the same ellipsoid, because the intersection of the two chloritic seams pitches east, whereas the dip of the vein fractures, and their intersection with either of the chloritic seams, is to the west. It is axiomatic that the intersection of any two of the three units of a strain ellipsoid must pitch in the same direction. It looks, therefore, as if movement took place on only one of the chloritic seams (Fig. 5) at a time, and in this case one of the vein fracture directions could be the complementary shear plane. Thus, if the NE–SW chloritic seam be considered as one shear direction, and the 602 E vein fracture as the other, the 604 vein and parallel repetitions would fit in for the theoretical direction as the tension fractures. But, as mentioned above, the 604 vein and parallel fractures show evidence of shearing and have not the characteristics of tension fractures in most places. They could, however, be taken as the complementary shear direction to the E–W chloritic seam in another strain ellipsoid in a later movement where the tension cracks of the first movement were used as the shear direction of the second. The tension fractures of the second movement would be the shorter, flatly west-dipping veins that do have the characteristics of tension veins as described above under (*f*).

THE ORE BODIES.

Ore in the Graywacke.—The graywacke ore at the Canadian Malartic has, in plan, the shape of a single-barbed arrow, the shorter NW–SE ore body forming the barb, and the main E–W ore zone being the shaft. The junction of the two ore bodies pitches east, about 65 degrees above, but flattening with depth. Actually at the projected intersection of the NW–SE fractures

and the E–W zone there is little or no ore, since a set of fractures, mentioned above, striking about N 30 to 60° E and dipping 55° E, cuts across the angle made by the two and the ore solutions appear to have followed these. This feature, although carrying a good grade of ore, tends to shorten the length of the NW–SE zone as it is followed down the dip and is cut off by running into the E–W zone. Thus the NW–SE zone only occurs between the surface and the third level. The presence of the NW–SE fractures, however, are felt below this in making a bulge at the west end of the E–W zone at and near the fourth level.

The main E–W ore body, east of where it is affected by the intersection of the other zone, continues on a vertical dip from the surface to below the third level where it begins to feel the influence of the Main Porphyry mass which, outcropping near the east boundary of the property, pitches west to come into the region of No. 1 shaft at about 600 feet below surface. Evidently the zone of brecciation was deflected south by the porphyry to extend roughly along and down its south contact. For this reason the E–W ore zone, even where it extends east of the influence of the drag-fold and NW–SE fractures, is in section roughly hook-shaped (Fig. 2, section C–C), although the relative importance of the NW–SE fractures and the porphyry mass in deflecting the ore zone is difficult to estimate. The influence of the porphyry is well shown in plan on the third level (Fig. 3) 1,400 feet east of No. 1 shaft, where the ore zone is sharply deflected to the south as it comes up against the wide part of the porphyry. Farther east the zone roughly parallels the south contact of the porphyry, cutting across any bulges of the latter and incorporating it into the ore material (Fig. 2, section D).

The structural control of the graywacke ore is thus composite consisting of (1), the main east-west brecciated zone extending through three properties for a length of at least 9,000 feet; (2) the drag-fold that locally influences the shape of the porphyry and concentrates the NW–SE fractures; (3) the NW–SE fractures themselves, and (4) the main porphyry mass which, by coming in at depth and to the east, deflects to the south the E–W zone, probably limiting it in depth.

The ore material itself consists of gray or buff brecciated graywacke, in which the bedding, and commonly the texture of the brecciation, is obscured by recrystallization, silicification and pyrite mineralization. Clear cut quartz veinlets are not common but a polished surface of the ore shows fine-grained quartz in irregular stringers and patches. Pyrite is evenly distributed and common, but nowhere forms "massive sulphide." Visible gold is distinctly rare in the graywacke ore. Under the microscope, the ore is seen to consist of graywacke recrystallized after brecciation, resulting in the biotite forming larger unit crystals, in the development of sericite needles, concentrated in patches, and probably in complete recrystallization of the feldspar. Throughout this material are fine stringers of quartz, coarser than the texture of the altered graywacke, and containing a minor amount of carbonate. Pyrite is disseminated throughout the whole, but is considerably more abundant in the quartz stringers. In some parts of the ore, as well as in parts of the brecciated zone not making ore grade, carbonatization is a relatively important process amounting to 15 to 20 per cent of the whole rock. Chalcopyrite, sphalerite and galena occur in minor quantities, as has been noted by O'Neill.[4]

A considerable amount of porphyry in disconnected lenses and torn shreds, generally much silicified, occurs in the ore. On the whole, the grade is higher where these remnants are abundant but the gold seems to have been deposited round their margins rather than in them, since assays from samples of the silicified porphyry itself, either from isolated lenses or from the main dike north of the ore, give low results in gold.

A fact that has become apparent during the last few years development is that commercial gold values are not directly associated with a high degree of silicification or other alteration, nor with high pyrite content. Many areas within the main east-west zone of brecciation showing a high degree of alteration and pyritization carry only sub-commercial values in gold, whereas ore is being stoped in parts of the zone having less than average alteration. It may be said in general that the solutions causing

the alteration and pyritization on the one hand, and those depositing gold (and probably some further silica) on the other, have both followed the same main zones of brecciation, but that the latter are confined between narrower limits and were probably deposited at a slightly later stage after a repetition of movement on the zones.

Ore in the Porphyry.—The ore found within the main porphyry body is completely different, both structurally and mineralogically, from that of the bodies in the graywacke (Fig. 7). The veins described below occur, with a few rare exceptions, only in the unsilicified porphyry, generally in the neighbourhood of definite graywacke inclusions or of the "chloritic seams." The ore material certainly bears a strong resemblance to pegmatite and the mineral association also shows some features in common with them, but there are some characteristics that exclude it from the strict use of the term. They do not occur as dikes with walls, but as fracture fillings and replacements; they do not show graphic intergrowth and there is very little feldspar that can be proved to have been precipitated from solutions. There is an abundance of red feldspar, especially in the margins, but much of this is clearly due to included fragments, which, together with the walls of the veins, have undergone the "red alteration," and any small proportion of precipitated feldspar would be hard to distinguish. That a small amount of the feldspar has been added, however, is suggested by the fact that in the graywacke, both within the ore bodies and outside them, are small stringers of quartz and a pegmatitic assemblage (some of which carry gold values, although not in commercial widths) and these have a small proportion of feldspar that could not be derived from porphyry inclusions. Excluding the feldspar, which is derived largely from porphyry inclusions, quartz (a white, glassy variety) is by far the commonest fracture-filling mineral, and many of the smaller veins consist only of quartz with a narrow selvage of red, altered porphyry. In the larger veins, however, a large number of minerals occur in smaller proportions, as shown by the following list:

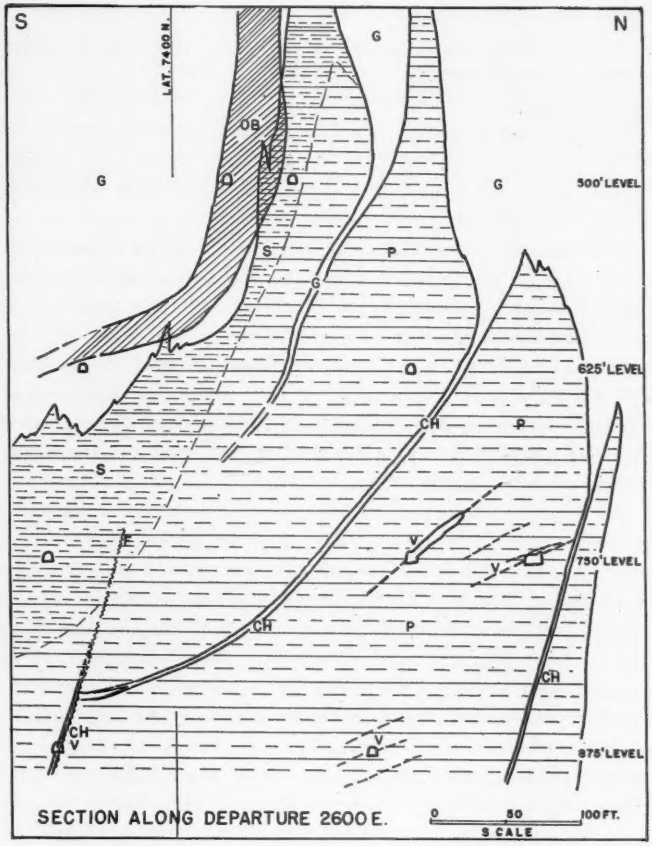

FIG. 7. Vertical section through the lower levels of the Canadian Malartic Mine showing the relationship between the main ore body in the graywacke and the veins in the porphyry. *G*—Graywacke, *P*—Unaltered porphyry, *S*—Silicified porphyry, *OB*—Main ore body, *V*—"Pegmatitic" veins in porphyry, *CH*—"Chloritic seams," *F*—Fault.

Very abundant:
Quartz
Albite and orthoclase (largely altered porphyry inclusions and walls).
Common in small quantities:
Chlorite, biotite, tourmaline, pyrite, and gold (rarely visible).
Fairly common locally:
Calcite, scheelite, rutile (dark, sub-metallic variety), muscovite.
Rare:
Molybdenite, fluorite, galena, specularite, tellurides (not definitely identified), selenite (in a seam, possibly supergene), soft red hematite (possibly supergene).

Although the gold values are somewhat irregular in the pegmatitic type of ore, the individual veins are of considerably higher grade than the graywacke ore. Visible gold, where seen, occurs on the borders of porphyry inclusions, around clusters of pyrite, and in places scattered through the glassy quartz. As a rule a high pyrite content indicates good gold values in this type of ore, but cases have been found where the pyrite, when assayed separately, yielded only a trace of gold, but in others the pyrite assayed up to 7 ounces per ton.

The fractures followed by this material and their relation to " chloritic seams " are described above under the heading " Structure." From exploration to date, the pegmatitic ore occurs in two types of bodies. The first occurs where a portion of the porphyry has been thoroughly shattered into closely spaced fractures and mineralized with the material described above, so as to make the whole area mineable. The second, and commoner, type is where the ore material has followed certain fractures to form veins that must be mined individually.

An example of the first type is seen on the fourth level (the most northerly ore body in Fig. 3, 4th level, and Fig. 2, section C). Here, a tongue of porphyry pinching out upwards, has become shattered along its north side, most of the fractures running northwest and dipping southwest at 40° to 70°. The fractures are filled with quartz and the other minerals listed above, scheelite being unusually prominent. In this particular case the porphyry in between the fractures is brecciated and altered and also carries low to medium values in gold. The individual veins assay from half an ounce per ton upwards and the whole mass forms an average grade of 0.25 ounces per ton.

The best example of a single vein of quartz and "pegmatite" is the 602 E. vein on the 6th level. The vein, with somewhat irregular walls, strikes S 74 E and dips about 40° S. The center is, in most places, quartz with a little coarse pyrite and biotite but the margins consist of red feldspar, the red alteration fading off into the normal gray porphyry, slightly pyritized but otherwise unaltered. The width of this vein varies from 6 inches to two feet but the stoping width is increased by smaller, quartz-filled fractures, possibly tensional, that break off the main vein in a regular set (Fig. 5).

At least two mineable veins and numerous smaller stringers follow a set of fractures striking N 10 to 30 W and dipping about 50° W. The fractures these follow are, like the last, apparently shear planes of small movement, showing slickensided surfaces, but associated with them are typical quartz-filled tension cracks, dipping flatly west and of an elongated lens shape. The structural relationship of these sets with the previous one is discussed in an earlier section.

The vein known as 605 (Figure 5) is a good example of tension cracks making up part of the ore. The ore in general strikes N 50 W and dips 45° SW. At the western end of the stope is a main vein following this direction but at the eastern end it gives place to a series of short veins each striking nearly north and dipping flatly west. The east end of the vein as a whole, and probably the bottom, ends against a narrow "chloritic seam," striking about east-west and dipping steeply south. In this case the "chloritic seam," the main vein and the tension cracks fit fairly well into the three theoretical components of a strain ellipsoid.

A fourth type of vein within the porphyry has recently been opened up on the seventh level. Here the south "chloritic seam," which on this level shows considerable shearing, has been partially replaced by quartz and other "pegmatitic" material carrying irregular gold values. There have evidently been at least two periods of movement, one of which preceded the quartz whereas the other was post-ore. Although not definitely con-

nected through, the strong fault that follows the hanging wall of the east-west ore zone in the graywacke is believed to follow this "chloritic seam" at this level. It is interesting to note that on the fourth level, where the fault cuts graywacke, short lengths of quartz follow it in places and with the quartz are small quantities of red feldspar, biotite and tourmaline. There is thus a possible connection between the ore in the porphyry and veins (but not the main ore) in the graywacke.

GENETIC RELATIONSHIP OF "PEGMATITE" AND GOLD.

It has been mentioned above that the veins in the porphyry have not all the textural characteristics of true pegmatite but that the two have a number of features in common. If it is assumed that the veins are at least closely related to pegmatites it remains to be settled whether the gold is an original consituent of the mineral assemblage or whether it was added later after refracturing. The gold is, from what little evidence is available, the latest, or one of the latest, minerals to be deposited, but this is generally the case in most auriferous veins. A further point of interest is that the gold in this type of vein is of much greater fineness, the gold-silver ratio in the porphyry being 6.28: 1 whereas that in the graywacke ore is 1.9: 1. In favor of the theory that the gold in the porphyry veins is more or less contemporaneous and genetically connected with the rest of the mineral assemblage are the following facts:

(1) Gold is generally absent in the fresh porphyry except where it is cut by stringers or veins of quartz or "pegmatite."

(2) There is a tendency for the best gold values to occur in veins rich in quartz and relatively low in feldspar, and in those parts of veins rich in the rarer minerals mentioned (scheelite, rutile, etc.), *i.e.* in the more highly differentiated parts of the "pegmatite."

(3) Gold is commonly, but not invariably, associated with pyrite, which is one of the latest minerals to be deposited.

On the other hand in some places "pegmatite" veins, even

some carrying the " rare " minerals, do occur carrying negligible values in gold. The irregularity of gold values, even in some of the commercial veins, might also suggest to some that the metal was a later addition. The question is one that can probably never conclusively be settled, but if it is hard to prove that the gold is part of the original vein-filling material, it is still more difficult to prove that it is a later addition. In discussing the matter with Dr. H. C. Gunning, who is one of those most familiar with the geology of the district, and several other geologists, the general opinion was that evidence favored the conclusion that the gold was deposited at the end of the same period and from the same solutions as the quartz and the rest of the pegmatitic minerals.

TIME RELATIONSHIPS OF THE TWO TYPES OF ORE.

Since the graywacke ore is all either in the graywacke itself or on the southern, silicified margin of the porphyry, and the second type of ore is almost entirely within the un-silicified porphyry, there is some difficulty in deciding the time relationships of the two. That the pegmatitic alteration in the porphyry is later than the silicification and other alteration along the brecciated zones is indicated by two lines of evidence:

(1) Isolated narrow stringers of pegmatitic material and quartz follow joint planes that cut sharply the brecciated and altered graywacke both within and outside the limits of ore grade as noted by O'Neill.[4] In one case a stringer of this type in the graywacke south of the east-west ore zone carried erratic values in gold up to 0.8 ozs. per ton.

(2) In the ore zone in the porphyry on the fourth level, although the porphyry is not truly silicified, there are some bands and stringers of cherty silicification similar to the silicification along the south margin, and these are sharply cut by the veins and stringers of glassy quartz and " pegmatite."

This evidence seems to show that the pegmatitic alteration is later than the silicification along the brecciated zones but it does not necessarily prove that it is later than the gold in these zones since it was shown above that the gold values are not directly

dependent on the alteration and pyritization and were probably added slightly later. It might be possible, therefore, that the gold was added to the brecciated and altered zones in the graywacke at the same time as it was being deposited with the pegmatitic material in the porphyry. The fact that the gold-silver ratio in the graywacke is 1.9: 1 whereas in the pegmatitic type of ore it is 6.28: 1 might be taken as evidence against the last suggestion unless the difference can be explained by thermal zoning, the silver being retained in the solutions until they had migrated outside the porphyry. It is possible that further work in the lower levels and to the east may throw light on this problem. In the following tentative time scale the period of gold deposition in the graywacke ore is put in the two alternative positions:—

Mine Area as a Whole.

(1) Main folding of the Temiskamian graywackes and lavas into major east-west folds. (Intrusion of diorite dikes?)

(2) Secondary folding due to more or less lateral movement on up-turned strata causing steep-pitching, south-side-east drag-folds.

(3) Approximately contemporaneous with last, intrusion of porphyries the form of which was partially controlled by the drag-folds.

(4) Fracturing resulting from continuation of the same stresses as formed the drag-folds causing (a) NW–SE shears, especially near the drag-fold, and (b) main east-west brecciated zone affecting the south contact of the main porphyry body.

Outside Main Porphyry Body	*Inside Main Porphyry Body*
(5*a*) Alteration including silicification and pyritization along above two zones in graywacke affecting some porphyry tongues. (Possibly with some sub-commercial gold values.)	(5*b*) Silicification along south contact of main porphyry, east nose of west porphyry, and along other localized zones.
(6*a*) Further slight movement within brecciated and shear zones. *Main graywacke ore gold deposition* (?) (first alternative)	(6*b*) Movement on "chloritic seams" accompanied by "red alteration" of some parts of porphyry, grading into,
(7*a*) Isolated small pegmatitic and quartz stringers along joints in brecciated zones and in graywacke outside them. *Main graywacke ore gold deposition* (?) along zones formed in (6*a*). (Second alternative).	(7*b*) Continued movement on "chloritic seams," formation of complementary fractures in porphyry, and deposition by replacement and fracture-filling of quartz, "pegmatite," and *gold*.

(8) Post-ore faulting on small scale, especially on east-west fault dipping south.

ACKNOWLEDGMENTS.

The writer is indebted to the officials of Canadian Malartic Gold Mines Ltd. for permission to publish the information contained in this paper, and to Mr. E. V. Neelands, General Manager, and to Mr. J. P. Millenbach, General Superintendent, for discussion and suggestions. Acknowledgment is due to Mr. H. Herz and Mr. W. White, of the Engineering Department, for the value of their observations and for their assistance in the collection of information. Dr. H. C. Gunning, of the Geological Survey of Canada, has given some valuable suggestions and criticism.

25 KING ST. W.,
TORONTO, ONT., CANADA,
Mar. 22, 1939.

THE RELATIONSHIP OF STRUCTURE TO PETROLEUM PRODUCTION IN EASTERN VENEZUELA.

WILLARD MILLER.

ABSTRACT.

This paper presents the relationship of oil production to structure in eastern Venezuela. The exploration and development are confined to the Maturin Basin, a geosynclinal area characterized by sediments ranging in age from Cretaceous to Recent. A thick blanket of Pleistocene and Recent deposits covers practically all of the oil formations. The present commercially producing fields are located near seepages, but the areas now being developed were located by scientific exploration.

Each of the developed fields is discussed separately giving attention to the operating problems and the technique developed in order to obtain the oil.

INTRODUCTION.

GEOLOGISTS generally believe that eastern Venezuela is the section of the country where new petroleum discoveries will be centered. Although this province now produces only 16 per cent of the marketed Venezuelan crude oil, the results of active exploration since 1934 support this opinion. The exploratory work is confined to the Maturin Basin, a region 300 miles long with an average width of 175 miles, a total area about the size of the state of Washington.

Eastern Venezuela is the area east of Caracas and north of the Orinoco River. On the north along the coast is the Caribbean range of mountains extending into the delta region of the east. To the south of the coastal range is plains country with an elevation rarely reaching 1,000 feet. Near the bordering mountains and highlands in the north the land rises into rolling hills, but on the average the Llanos comprise an almost level surface of alluvial material comparable in topography to the terrain of the Pampa of Argentina. North of the Orinoco River a series of low sandstone mesas constitute the major relief.

Physically, the 9,000 square miles of the Orinoco Delta stand out as a distinct unit of jungle country. An interesting feature of the region is the innumerable distributaries of the Orinoco River, which form a network of waterways necessitating the use of boats in travelling.

STRUCTURE.

The outline of the Maturin Basin is not so well defined as is that of the Maracaibo Basin. The margin of the basin as defined by Dr. Guillermo Zuloaga, of the Venezuelan Geological Department is assumed as following a line that passes approximately through Guanoco, Aragua de Martin, San Mateo, Aragua de Barcelona, Pariaguan, halfway between La Canoa and Ciudad Bolivar, Barcabcas, and Cano Socupano.[1]

The Maturin Basin is a part of a conspicuous geosynclinal area that is bounded on the south by the Guiana Highlands. The northern limit of the geosyncline is difficult to establish. It may coincide with the southern limit of the Caribbean range of metamorphic rocks or quite possibly may be even north of this line. The segregation of the Maturin Basin within the geosyncline is, like the Maracaibo Basin, the result of a possible complicated development of sedimentation and tectonic movements.

The present area of exploitation and the region of most active exploratory drilling, is covered by the Llanos formation, a thick blanket of Pleistocene and Recent deposits. Exposure of older rocks occur only in the extreme north and the extreme south portions. In the north, the hills of the Caribbean Range protrude through this blanket of Llanos and show, in the main, well folded Cretaceous and Eocene beds with a strip of folded Miocene beds along the edge of the foothills. In the south, exposures first occur along the banks of the Orinoco. These consist of metamorphic schists, quartzites, and plutonic rocks, and they are covered immediately to the north by a blanket of Llanos deposits that thicken northward as the basement gradually plunges in that direction. The knowledge of this region is based entirely on

[1] Willson Co.: Exploratory work in Venezuela—Across delta jungles and plain. Oil and Gas Jour., 37: 14–17, 1938.

the results of geophysical work and exploratory wells. It appears that the base plunges northward in a series of undulating slopes and terraces, and that successive members of the Miocene beds are overlapped southward by the gently dipping Pliocene and Recent deposits. The northerly plunge continues for about 60 miles to a deep basin south of Maturin, and actual folding can be proved only in this region.

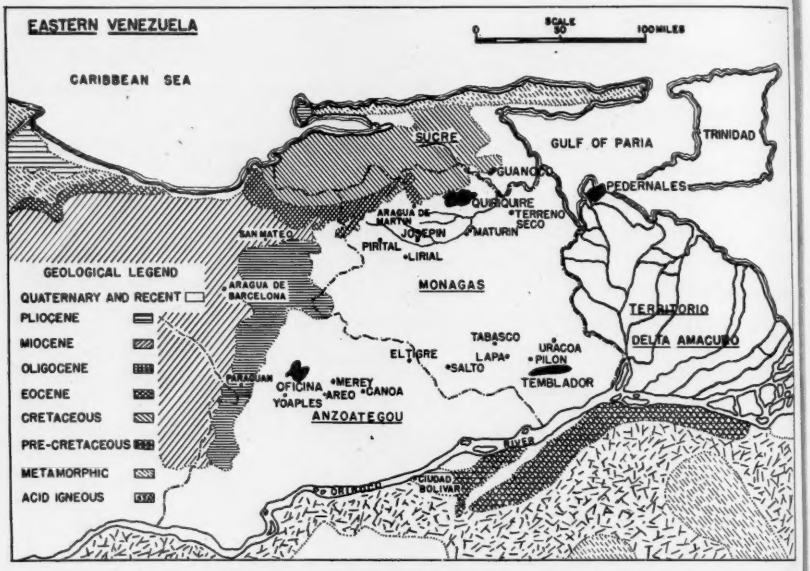

FIG. 1. Geological map of eastern Venezuela with location of shipping fields, wildcat tests, and principal operating centers. (Courtesy of Ministero de Fomento, Venezuelan Government.)

The geological sequence of the Oligocene and younger formations of the Maturin Basin is not so well known as it is in Trinidad. The following tentative classification is presented by Professor V. C. Illing and H. G. Kugler.[2] The main episodes of the geological history of the area are as follows:

[2] Illing, V. C., and Kugler: Eastern Venezuela. Sci. of Petr., 1: 108–110.

(*a*) The deposition of an extensive Cretaceous series of grits, limestones, and shales, followed by thick sandstones of Eocene age.
(*b*) A possible but not fully proved episode of clear shallow water of Upper Eocene-Lower Oligocene Age.
(*c*) Extensive but gradual depression of the main basin with a depositional overlap of the Upper Oligocene and Miocene. It is probable that a considerable folding movement separated stages (*b*) and (*c*) in the north.
(*d*) The later stages of in-filling were associated with a more sandy facies with extensive subsidence in the north and the formation of thick masses of sandstone and shales, followed by folding movements in the northern area.
(*e*) The whole basin was covered with a blanket of Llanos deposits of terrestrial origin. These deposits consist largely of alluvial cones formed at the edge of the foothills, grading southward into great sheets of alluvial clays and sands over the main Llanos.
(*f*) The final stage consisted of a considerable upward movement associated with a partial dissection of the Llanos deposits near the foothills.

GUANOCO FIELD.

The Guanoco field, located in the District of Benitez, state of Sucre, was the first field to be explored in Venezuela. The first well, completed in September 1913 by the New York and Bermuda Company, was drilled near Lake Guanoco, which covers approximately 1,100 acres of the surface of the field with a six foot layer of asphalt. The field has an anticlinal structure extending N. 70° E. in which the producing formation is the Guayuta shale of lower Cretaceous age. The shales, when freshly exposed in the foothill regions, show considerable evidence of petroleum, and where they have been covered by sands of younger age they have impregnated the latter with asphaltic oil.

From 1914 to 1916 ten wells were drilled in the field, but the production was not large enough to warrant further commercial development. The wells were shut in, and it was not until 1925 that any additional drilling was done. As of January 1, 1939 there had been 24 wells completed, 15 of which were shut in producers, the production being too small to operate on a commercial basis. The average depth of the wells is 1,300 feet, and the average gravity of the oil is 10.49° A. P. I. asphalt base. The total production from the Guanoco field from 1913 to January 1, 1939 was 1,718,150 barrels.

QUIRIQUIRE FIELD.

The Quiriquire field, in the District of Piar, State of Monagas, lies southwest of Caripito between the Azagua and Quiriquire Rivers. The pioneer company in recognizing the possibilities of this region, and in financing the expensive preliminary exploration was the Standard Oil Company of Venezuela, which is owned wholly by the Creole Petroleum Corporation, a subsidiary of the Standard Oil Company of New Jersey. Its field parties penetrated a practically virgin area of swamp and jungle that contained only a few widely scattered farming and ranching communities, partially worked out the structure, and made locations for a series of wildcat wells.

The structure appears to be a monocline dipping about 10° SSE. At the northern edge of the field a strike fault with a southern downthrow occurs, and cross faults are common. These are marked by oil seeps, hard asphalt dikes, and the occurrence in places of shallow oil production near them. From the seepage indications, the discovery well was drilled in 1925. A north-south fault divides the field into two parts, designated as the west segment, and east segment, respectively. In the east segment there are two distinct producing zones, separated by a shale bed, which yield oil in most cases from different wells by the use of twin locations. The largest amount of oil comes from this division. In the west segment there is only one zone, the oil from which is of lower quality than that on the other side of the fault.

The developed area trends N. 70° E. It is approximately 6.2 miles long and about 3.7 miles wide. The production comes from the Quiriquire formation of Pliocene age, which is correlated with the La Brea beds of Trinidad, and attains a thickness of 3,300 feet in the southern part of the field. Inspissated oil is found throughout the Quiriquire formation, but the main production is from the lower 600 feet. These horizons are not homogeneous but consist of irregular and lenticular beds of sand and conglomerate, interspersed with shales. The producing sections vary greatly in thickness with water above, below, and in

places in intermediate zones. Cross correlation is extremely difficult due to the lenticularity. The producing beds rest unconformably upon Upper Miocene black shales. Toward the north, they overlie petroliferous Eocene and Cretaceous formations. The oil is almost certainly migrant, and may have been derived from the Cretaceous, or alternatively from Miocene or Oligocene beds farther down the flanks of the main line.

The standard rotary rig is used in the Quiriquire field. Most of the locations have to be cleared from the "Monte," and steam shovels are necessary in preparing many of the well sites. Well locations in swamps and dense jungles have led to experimentation with diesel and diesel-electric drilling units. Because of the low fuel consumption and reduction of bulk in transportation, the diesel seems to have proved useful in locations far distant from the main base of operation.

In drilling, fish tail bits are used to a depth of about 2,000 feet. After the conglomerate is reached, the cutting is somewhat difficult and will dull any bit. Drag bits have been used to some extent, but the present practice is to use the roller type rock bit.

An interesting feature in the development of the Quiriquire field is the use of "twin wells" at many locations. In drilling twin-location wells, the first well goes through the entire productive horizon and all producing sands are cored. The casing and liner is then set to produce the lower zone in this well. In the second well it is not necessary to core, the location of the shale break between the upper and lower zones and other data being known from the log of the first well, which is only 30 feet distant. The second well is not drilled beyond the shale, and casing and liner are set to produce from the upper zone. Total depths of the upper sand walls average 2,500 feet, lower sand walls average 3,000 feet.

While the first well is being drilled the derrick for the second is erected. After the first well is completed, the engines, drawworks, table, and remainder of the rig are moved and all connections changed. The boiler remains in the setting used for the first well, and the pumps are placed where desired. The derrick for the first well is then moved away.

The casing program for the twin wells is as follows: A surface string of 13⅜ inch casing is cemented at 350 feet from top to bottom. From this point an 8⅝ inch string is run to the top of the producing horizon with a 4¾ inch perforated liner entering the productive sands.

The practice of using twin wells has worked out satisfactorily. It has lessened the danger of water intrusion, gas migration, and the proper production control of the various component sands in the producing wells. In various cases, one twin has been invaded by water or gas without effect on the other, and at one location the lower twin is used as a repressuring input well, while the upper twin is used for production.

The average completion time for the majority of the wells drilled is about 45 days. The depth of the wells is from 1,800 to 3,250 feet, with an average of 2,800 feet. There are 247 wells completed, of which, 160 are flowing naturally, 35 pumping, 35 closed-in, 6 inactive, and only 11 have been abandoned. The small percentage of failures is one of the remarkable aspects of the field. Most of the wells have been drilled in the east segment because of the higher gravity oil obtained there. The early wells were spaced on a 900 foot location, but as the production area grew the wells were spaced 2,900 feet apart to determine the edges of the field. The proved area has been set at approximately 12,680 acres, but some extensions in the future seem probable.

The aim of the company in producing the field is to maintain the maximum efficiency and to obtain the highest ultimate yield. The company prorates itself, production controlling the tanker schedule rather than the tanker schedule governing production. The gas-oil ratio averages about 200 cu. ft. per barrel, and there is no free gas, it being conserved to the utmost.

In the west segment, where there is only one zone, the pressure has declined 57 pounds to the present pressure of 1,193 pounds per square inch. In the east segment, the pressure in the upper zone has dropped only 27 pounds to a present pressure of 1,038 pounds per square inch. The pressure in the lower zone,

which has been drilled up faster, has dropped only 50 pounds to a present pressure of 1,211 pounds per square inch. All pressures are corrected to 2,600 feet subsea datum.[3]

Repressuring operations have been carried on in the field since 1932. Gas from the separators is carried to a compressor station. The daily capacity of the plant is about 7,000,000 cubic feet with an intake of 53 pounds and a discharge pressure of 1,100 pounds per square inch. In the repressuring operation two wells are used. The input well can be changed around when it is found to be desirable, and in some instances after these wells have been put back on oil production, they produce quite well. It is believed that repressuring has maintained the pressure in the field as well as providing other production advantages.

The Quiriquire field yields the largest production in eastern Venezuela, and holds fourth place within the country. The average daily production is about 70,000 barrels. Production during 1938 amounted to 25,330,610 barrels as compared to 25,879,944 barrels in 1937. The cumulative total for the field from 1929 to January 1, 1939 is 124,118,228 barrels.

PEDERNALES FIELD.

The Pedernales field, owned and operated by the Standard Oil Company of Venezuela, is located near the south shore of Cano Manamo, the most northerly mouth of the Orinoco River. The discovery well was drilled in 1933, and had a blow out of gas and oil at 1,550 feet depth.

Because of the recency of development, the geological structure of the field has been only partially determined. In general it appears to be an anticline that is faulted on both flanks. The wells are drilled into the Forest-Cruise formation of Miocene age. Tectonic complexities in this area are comparable with those of the Cedros Peninsula in Trinidad.

The development of the field is greatly complicated by existing surface conditions, chief of which is the absence of dry land. Several of the present wells are on pile foundations in Cano

[3] Sawdon, W. A.: The Quiriquire field. The Petr. Eng. 8: 103–108, 1937.

Manamo, which at that point is about 35 feet deep. The remaining wells are on Isla Cotorra, a low swampy piece of delta land that is completely submerged during high tide. As a result, all construction off shore, including flow stations and well foundations, must be on piling, and marine equipment must be used for transportation. On shore, timber mats or piling must be used to provide foundations, and a narrow gauge railroad on a pile supported trestle must be constructed from the landing pier to each well location or station site. The resultant operating cost is naturally high compared with operations on solid ground.

Drilling problems are numerous and varied. After driving 20 inch welded steel piles and capping them with a steel structure and a 122-foot derrick, special drilling equipment must also be provided for marine operation. All wells are now drilled with heavy type diesel-electric rotary outfits. The diesel-electric unit is mounted on two barges. Power is generated by three 260 horsepower diesel engines connected with D. C. generators and exciters. These supply current to a 150–300 horsepower motor that operates the drawworks and rotary. The power driven mud pumps, which are mounted on a second barge complete with mud pit, reserve mud storage, and cementing equipment, are each driven by 150–300 horsepower motors. The mud barge has a heavy second deck above this equipment that serves as a pipe rack for drilling operations. The water supply for drilling and other purposes is a serious problem, since Cano Manamo is a tidal river, which at Pedernales carries salt water during the winter months, and is brackish much of the time. After exhausting local possibilities it was necessary to build a 40 kilometer waterline through swamp land, and a water pump station to provide sufficient water for the operations.

There are many difficulties to overcome after drilling has begun. The steep dip of the strata makes it necessary to use high rotating speeds and light weights on the bit to avoid wide deviations from the vertical. Both rock and drag bits are used.

The casing program followed in the Pedernales field is 200 feet of 18⅝ inch of surface pipe, 2,300 feet of 13⅜ inch inter-

mediate string, and 5,300 feet of 9⅝ inch oil string with a 4¾ perforated liner.

Close production control, exercised on all wells, prevents excessive decline in reservoir pressures and resultant increase in gas-oil ratio. The wells have initial pressures up to 3,300 pounds per square inch, but usually decline rapidly to approximately the equivalent of the hydrostatic head, when there is a perceptible falling off in sub-surface pressure decline.[4]

In the Pedernales field, thirteen wells have been completed proving an area of 800 acres and giving a daily production of 5,000 barrels. The field is about 2.5 miles long and ¾ mile wide with the major axis extending northeast-southwest. The oil has a gravity of 21.2° A. P. I. Wells are between 5,000 and 6,000 feet deep. The first crude was issued on the market in October, 1936, and the cumulative total for the field to January 1, 1939 was 3,435,119 barrels.

RECENT EXPLORATION.

There probably is no place in the oil world where exploratory work is more active than in eastern Venezuela. The wildcat exploration, although scattered over a broad area, has been directed in a southwesterly trend from the fields of Trinidad and Quiriquire across southern Monagas and trending approximately parallel with and 40 to 60 miles north of the Orinoco River.

The dense jungle growth, known locally as "Monte," makes geological work in the delta of the Orinoco extremely difficult and hazardous. Geophysical work is being carried on in all of the more promising areas, and torsion balance parties have secured fair results in this region. On the open Llanos, parallel lines have been run at 5 to 7 kilometer intervals, but in the brush only the main roads have been surveyed. Seismographic work has been done largely on the Llano because the sand and gravel covering prevents the geologist from working on the surface of the ground.

It is estimated that there are 40 crews working in the Maturin

[4] Pedernales field in eastern Venezuela becomes important. Oil and Gas Jour., 36: 74, 1937.

Basin. They include 12 geological crews; 4 magnetometer, 9 gravity, and 14 seismograph. The gravity methods include torsion balance, Banberg balance, Rainbow balance, Thyssen and other gravitymeters. There is an Eltran party. In addition, at least two structural core-drilling rigs are at work. Some of this work in the plains country is restricted by the seasons. The rainy season extends from April to October and the dry season from November to March. The rains in the interior are in the form of thunderstorms, and only rarely do they cause a party to lose an entire day.

RECENT DEVELOPMENTS.

The Temblador wells in the District of Sotillo, State of Monagas are owned by the following companies: Standard Oil Company of Venezuela, Lago Petroleum Corporation, Pantepec Oil Company, all subsidiaries of the Standard Oil Company of New Jersey, and the Mene Grande Oil Company, a Gulf Oil Corporation subsidiary. Operations are conducted by the Standard Oil Company of Venezuela.

The field was opened in April, 1937, by the completion of No. 1 Yabo. The depth was 3,994 feet and initial production 575 barrels. The gravity of the oil was 20.2° A. P. I. Since then 40 wells have been completed, all flowing and producing about 7,500 barrels per day. The average depth of the wells is between 3,900 and 4,000 feet. The proved area is now about 4,300 acres. The axis of the field is northeast-southwest and as determined by drilling is about 19.2 miles long by less than ½ mile wide. Production is from the upthrow side of a normal fault, the length of which has not been determined. The oil is from sands of middle Miocene age.[5]

All wells are drilled by steam powered rotary outfits. Steel derricks and foundations are used and skidded from one location to another. Engine bases, engines, and engine house are skidded in one piece. Slush pumps and pipe racks are skidded in sections. The complete rig can be moved in 30 hours.

[5] Service on Venezuelan fields. Oil and Gas Jour., 38: 77–81, 1938.

The casing program is 175 feet of 13¾ inch surface pipe, 1,500 feet of 9⅝ inch intermediate pipe and 3,400 feet of 7 inch or 3,900 feet of intermediate casing, which is gun perforated opposite the sand. If a short string of 7 inch is used, a 4¾ inch perforated liner is set. Before running the oil string the hole is electrically logged and then the casing is run and gun perforated.

As soon as the well is brought in, the derrick and other equipment are moved to another location. With the structures removed from the flowing wells and the operations scattered over a wide area the field lacks the appearance of an active region.

About 125 miles west of the Temblador area are the Oficina wells operated by the Mene Grande Oil Company. This is an undeveloped area with only six wells drilled and four producers completed, of which two produce sufficient oil for fuel for drilling and other purposes. At present the company is in the midst of a major construction program that is scheduled to bring Oficina crude oil to Guanta through a 16 inch pipe line, by September, 1939.

All wells are being drilled with steam powered rotary outfits adapted to use on the local terrain. Six rigs are drilling at the present time. Special drilling mud and admixtures are used as needed. Flowing pressures on wells vary from 100 to 500 pounds per square inch. The casing program is to run 1,800 feet of 13¾ inch, or 10¾ inch, casing per upper water shut off and then to reduce the hole and set an oil string of either 8⅝ inch or 7 inch, and gun perforated opposite the producing formation. The proved area covers a section about 3 miles square. The crude is exceptional in that it runs from 37° to 40° A. P. I. gravity.

CONCLUSION.

The Maturin Basin is a large geosynclinal area characterized by sedimentary rocks dating from Cretaceous to Recent. Within this basin are several producing horizons. The thick blanket of Pleistocene and Recent deposits has covered practically all structural evidences of the oil formations. The commercially producing fields were developed near seepages where the oil had

reached the surface through joint and fault planes. In exploring for new fields scientific methods are a necessity because the surface terrain conceals the underlying structure.

Each of the producing fields has operating problems that require special attention, and in some cases the introduction of unique producing methods. An example is the Quiriquire field where twin location wells are drilled to secure production from two distinct producing formations. The processes developed are economically important; they are necessary in order to obtain the crude oil, and they illustrate how an industry must take into consideration the natural environment.

The geological structure of eastern Venezuela is only partially worked out at the present time because of the recency of discovery. From the reports of geophysical and geological parties the Maturin Basin is one of the most promising oil areas in the world, and it is only a matter of time until several new fields will be producing on a commercial basis.

UNIVERSITY OF NEBRASKA,
LINCOLN, NEBRASKA,
March 20, 1939.

ACTION OF ALKALI SULPHIDE SOLUTIONS ON MINERALS AT ELEVATED TEMPERATURES.

J. L. LINDNER AND JOHN W. GRUNER.

ABSTRACT.

Since alkali sulphide solutions are frequently considered to be ore carriers, their action on minerals of the country rock, particularly iron-containing ones, was investigated. All experiments were made at temperatures of 300° C. in gold-lined bombs. The time of each was approximately one week. Numerous alteration products were obtained; many of them were positively identified. Others, due to the minute quantities obtained could not be recognized. Solutions of H_2S and NaHS commonly alter the iron in the original minerals to pyrite, while Na_2S produces iron oxides and black FeS. Other minerals produced were marcasite, quartz, chalcedony, opal, analcite, albite?, chlorites, acmite, sericite?, chrysotile, anhydrite, sulphur, and gold crystals. Kaolin minerals and nontronite were probably among the alteration products.

INTRODUCTION.

In view of the interesting results obtained recently by Stevens,[1] Gruner,[2] Ogryzlo,[3] and others with alkali sulphide solutions, it was thought desirable to extend these hydrothermal experiments to various common iron-bearing minerals and note typical alterations. It was thought that perhaps by supplying sulphur at elevated temperatures in hydrothermal solution, some of the iron might be dissolved and reprecipitate as pyrite, which is so common in veins. With this end in view, experiments were made using sodium sulphide, sodium hydrosulphide, and hydrosulphuric acid solutions.

The writers are indebted to Professor F. F. Grout for aid in the identification of some of the alteration products, and Dr. R. B.

[1] Stevens, R. E: The alteration of pyrite to pyrrhotite by alkali sulphide solutions. Econ. Geol., 28: 1–20, 1933.

[2] Gruner, J. W.: The solubilities of metallic sulphides in alkali sulphide solutions. Econ. Geol., 28: 773–777, 1933.

[3] Ogryzlo, S. P.: Hydrothermal experiments with gold. Econ. Geol., 30: 400–425, 1935.

Ellested, who has contributed many valuable and helpful suggestions.

The work was made possible by the aid of the Graduate School of the University of Minnesota.

PREVIOUS WORK.

Alkali sulphides have long been cited as solvents of pyrite, pyrrhotite, and other metallic sulphides. S. F. Emmons,[4] as far back as 1886, stated metallic sulphides are soluble in alkali sulphide solutions or those of sulphurated hydrogen. Becker,[5] Doelter,[6] Freeman,[7] and others agreed, and stated that iron sulphides are soluble in either hot or cold aqueous solutions of sodium sulphide (Na_2S), being carried into solution as the double sulphide of the heavy metal and the alkali ($FeS \cdot Na_2S$).

Becker found that one part of pyrite dissolved in 1800 parts of 1.5 molar Na_2S forming a deep green solution. Freeman found the double sulphide of iron and sodium, $FeS \cdot Na_2S$, obtained by fusing the sulphides together, to be completely soluble in water. He believed that double sulphides in nature might be transported in solution until they were decomposed by oxygen, carbon dioxide, or other reagents to form ore bodies.

It is probable the high solubilities reported by the earlier workers refer to colloidal solutions. The true solubility of the iron sulphides is, it is now believed, considerably smaller.

Experimental work by Foreman[8] indicated that neither pyrite nor pyrrhotite is soluble in Na_2S solutions at high temperatures and pressures. Schouten[9] in his work on synthetic replacements

[4] Emmons, S. F.: Geology and mining industry of Leadville. U. S. Geol. Surv. Mon. 12: 563, 1886.

[5] Becker, G. F.: Geology of the quicksilver deposits of the Pacific Slope. U. S. Geol. Surv. Mon. 13: 432, 1888.

[6] Doelter, C.: Einige Versuche über die Löslichkeit der Mineralien. Min. pet. Mitt., N.S. 11: 321–324, 1889–90.

[7] Freeman, Horace: The genesis of sulphide ores. Eng. and Min. Jour., 120: 973–975, 1925.

[8] Foreman, Fred: Hydrothermal experiments on solubility and oxidation of iron and copper sulphides. Econ. Geol., 24: 837, 1929.

[9] Schouten, C.: Structures and textures of synthetic replacements. Econ. Geol., 29: 636, 1934.

found that pyrrhotite apparently remained unaltered in a solution K_2S_x. The concentration was unknown, being termed merely "concentrated."

Stevens,[10] however, stated that pyrrhotite dissolves in Na_2S forming a dark green solution, probably colloidal. The nature of these green solutions, as obtained by him, Becker, Freeman, and others was suggested by Horsch.[11] He assigned the formula $4Na_2S \cdot FeS$ to the colloidal product. Stevens obtained no solution of either pyrite or pyrrhotite with sodium hydrosulphide solutions (NaHS). He believed that the negative results obtained by Foreman[12] were due to his having had solutions of NaHS rather than Na_3S. Gruner[13] pointed out that Foreman did his experimental work in the presence of much silica, always present under natural conditions and, therefore, these experiments should have geological significance. Hot alkali sulphide solutions do not seem to be stable in the presence of silica due to the formation of alkali silicates such as is shown by the equation

$$2Na_2S + SiO_2 + H_2O \rightarrow Na_2SiO_3 + 2NaHS.$$

Where silica is absent, solution may take place.

Alkali solutions should, however, cause a very decided *alteration* of iron sulphides. Stevens pointed out that since the nearly complete hydrolysis of Na_2S forms a strong base and very weak acid, as shown by the equation below, the hydrogen ion concentration would be well on the alkaline side.

$$Na_2S + H_2O \rightleftarrows NaOH + NaHS.$$

H. N. Stokes[14] was able to convert pyrite and marcasite into hematite by the action of alkali hydroxides. This reaction was carried out without the presence of free oxygen as shown by the

[10] Op. cit., p. 5.

[11] Horsch, S. M.: Sur le Sulfure Double Colloidal de Fer et de Sodium. Bull. Soc. Chim. de France, 27: 777–779, 1920.

[12] Op. cit., p. 837.

[13] Op. cit., p. 774.

[14] Stokes, H. N.: Experiments on the action of various solutions on pyrite and marcasite. ECON. GEOL., 2: 14, 1907.

equation

$$8FeS_2 + 30NaOH \rightarrow 4Fe_2O_3 + 14Na_2S + Na_2S_2O_3 + 15H_2O.$$

Stevens [15] found that alkali solutions in the absence of silica acting on pyrite formed pyrrhotite and a polysulphide according to the equation

$$xFeS_2 + Na_2S \rightleftarrows Na_2S_{(x+1)} + xFeS.$$

Thus, the final product here depends on the ratio of the alkali sulphide to the polysulphide. He concluded that if ferrous salts are acted upon by a solution of H_2S or of alkali sulphides, pyrrhotite would naturally form first. However, any oxidation or reaction tending to liberate sulphur from the Na_2S would favor the formation of Na_2S_2 and thus pyrite.

EXPERIMENTAL WORK.

Apparatus Used.

Because of the corrosive action of the solutions, it was imperative that any closed system in which these reactions could be run, must be so constructed and of such material as to be unaffected or but slightly so by the solution present.

For hydrothermal experiments of this nature, gold lined bombs had been constructed and previously used with success by Ogryzlo,[16] Gruner,[17] and others. These have been fully described elsewhere. Briefly they are bombs of 50 cc. capacity constructed of tool steel. They are lined with 24 carat gold and are sealed on the top by a gold sheet that fits against the flanges of the lining. The bombs were filled half full with solution, unless stated differently.

The hydrothermal experiments, all of which were carried out at 300° C., were performed in a large oven type furnace with a Bristol Company thermostatic control. The variations of the furnace

[15] Op. cit., p. 16.

[16] Op. cit., pp. 400–415.

[17] Gruner, J. W.: Hydrothermal oxidation and leaching experiments. ECON. GEOL., 25: 711–714, 1930.

were found to be not more than $\pm 3°$ C. The pressures developed in the experiments should be somewhere near 85 atmospheres, the vapor pressure of water at 300° C.

Hydrogen sulphide was generated with a Kipp generator using 1:1 HCl on FeS, and the gas was passed through distilled water before being introduced into the experiment to preclude any acid from entering the solution.

Baker's sodium sulphide in chemically pure crystals was used ($Na_2S \cdot 9H_2O$). The weights taken are necessarily approximate due to the deliquescent property of the salt. The solutions were made up in most of the experiments with 5 grams of the salt per 25 cc. of distilled water (0.83 molar). The air in these experiments was displaced with H_2S by holding a drawn out glass tube just above the level of the solution in the bomb and allowing the gas to pass with a uniform velocity for about a minute. In this way probably only traces of H_2S went into solution.

The sodium hydrosulphide solution was made up similarly to the solution of sodium sulphide. However, H_2S was allowed to bubble freely with a uniform velocity through the solution in the bomb for a considerable length of time, sufficient to allow the reaction given below to attain equilibrium at 25° C.

$$Na_2S + H_2O \rightleftarrows NaHS + NaOH,$$
$$NaOH + H_2S \rightleftarrows NaHS + H_2O.$$

The air was of course displaced above the solution by the H_2S.

The hydrosulphuric acid solution was obtained by bubbling H_2S freely with a uniform velocity through distilled water until saturation had taken place. The air was displaced by the H_2S.

All water used was boiled vigorously for 10 minutes just previous to its use in order to drive out all dissolved air since any oxidation of alkali sulphides or hydrosulphides would form polysulphides.

After preparing the solution, the bomb was quickly sealed with a thin circular sheet of 24 carat gold. About two hours were required for the cooling of a bomb.

After the removal of the solution and of the altered mineral

section at the end of each experiment, the bombs were well washed with HCl, and then with water. The solution was tested for iron, gold, and in some experiments, silica. The mineral section was washed, dried, and examined microscopically.

Minerals Used.

Fourteen minerals were used in the experimental work.

A brief description of each specimen follows. For most of them analyses may be found in the literature.

Augite.—Locality, unknown; short prismatic black crystals. In thin section, color olive green; pleochroism weak, and interference colors of a medium order; minute impurities of calcite; extinction angle 45°. Fractures crossing the mineral showed no signs of alteration.

Hornblende.—Variety, pargasite; locality, Luckow, Bohemia (near Bilin); good translucent brown crystals. In thin section, color light brown, pleochroism strong, birefringence weak to moderate; extinction angle approximately 18°. No impurities were observed.

Olivine.—Locality, Webster, Jackson County, North Carolina; a pale green granular or sugary variety showing impurities of chromite.

Fayalite.—Locality, Rockport, Mass.; translucent brown variety. In thin section: color, pale yellow brown; birefringence and relief extremely high; the pleochroism weak. A fine dusty network of magnetite in fractures was seen throughout the specimen. No other impurities were observed.

Serpentine.—Variety, Verd-Antique; locality, Roxbury, Vermont; massive finely crystalline olive-green variety. In thin section: color, olive green; pleochroism and birefringence, weak; interference colors moderate. Fine veinlets of carbonate were found throughout the specimen, also local areas of disseminated magnetite. No sulphides were observed.

Antigorite.—Locality, Antigorio Valley, Piedmont, Italy; waxy olive-green lamellar; in thin plates, semi-translucent with an olive green color; pleochroism and birefringence, weak; interference colors, moderate. No impurities were observed.

Garnet.—Variety, Almandite to pyrope; locality, North Creek, New York; deep red translucent variety. In thin section: high relief with a color of pink to crimson; index of refraction, 1.760, and specific gravity, 3.9. No impurities were observed in the sections.

Biotite.—Locality, Sebastopol, Renfrew Co., Ontario; a smoky dark brown to black variety; in thin plates, transparent; the basal plates in

oils showed no pleochroism and weak birefringence; mean index of refraction, 1.624. No impurities were observed in the selected plates used.

Chlorite.—Variety, clinochlore; locality, unknown; platy, clear, pearly green variety; in thin plates, pale green; birefringence and pleochroism weak; interference colors, rather high. No impurities whatever were visible.

Chloritoid.—Variety, Masonite; locality, Natick, R. I.; fairly pure, dark gray-green variety. In thin section: color, pale-blue to gray-green; pleochroism, strong, with interference colors of a low order and birefringence weak. No impurities were observed.

Siderite.—Locality, Roxbury, Conn.; light-brown, coarsely-crystalline variety, showing typical curved faces; traces of limonite along fractures and, locally, minute cubes of galena.

Magnetite.—Locality, Kinney (Mesabi Range), Minn.; dense finely crystalline steel gray variety of exceptional purity; traces of limonite only impurities present.

Hematite (Fe_2O_3).—Locality, (1) Republic mine (Marquette range), Mich., (2) Soudan mine (Vermillion range), Minn.; the hematite from locality (1) was a granular steel gray type showing no impurities, that from locality (2) was a massive dense steel gray variety, also showing no impurities.

Orthoclase.—Variety, adularia; locality, Pfitsch, Tyrol.

In order to facilitate an examination of the optical properties of the minerals both before and after treatment, thin sections of the minerals were used. For the most part they were ground to a somewhat greater thickness (about 1/10 mm.), than in normal optical work. This enabled the section to hold together better in contact with corrosive solutions than if a thinner slice had been used, and it did not greatly increase the difficulties of optical examination. In several micaceous or platy minerals, it was thought unnecessary to section them as they could be split into thin slices.

Each mineral was thoroughly examined before the start of an experiment and an original was retained for future reference or re-examination.

A section or several fragments of a section averaging about 1 cm. square was found to be ample material for an experiment.

Analytical Methods Used.

The presence of any H_2S in freshly opened bombs was established by testing with lead acetate on moist filter paper.

Where the presence of a sulphide was suspected, a small quantity of the solid material was boiled in a test tube with 1:1 HCl, and any H_2S escaping was noted as above. Then, a little granulated zinc was added as a reducing agent and the fumes were again tested. Although a ferrous sulphide would be decomposed without a reducing agent being present, it was found that much of the pyrite would also decompose because of its fine state of division, so that this test for distinguishing which variety of iron sulphide is present must be regarded in many instances as unreliable.

The solution was filtered and split into two portions. Any fine precipitate in the solution removed was tested further to determine its nature.

A portion of the solution was tested qualitatively for iron so that an approximate estimate could be formed of the amount in solution by the color of the reaction. The solution was concentrated to ½ its volume, acidified, and boiled to remove the H_2S and coagulate the sulphur. After filtering, the filtrate was oxidized with a few drops of H_2O_2. Excess ammonium thiocyanate was then added and the typical red color of the complex $Fe(CNS)_3$, ferric thiocyanate, obtained, if any, were present. If very weak, the color was concentrated by shaking with a little ether. This reaction is extremely sensitive.

Qualitative tests for gold in solution were made to extend the solvent action of alkali sulphides on gold, as established by S. Ogryzlo.[18]

In several instances quantitative determinations of gold were made. The gold was converted to the chloride, as before, and then precipitated with H_2S. It was then annealed and weighed.

Experiments with Hydrosulphuric Acid.

A number of experiments were made with hydrosulphuric acid at 300° C. and corresponding pressures (Table 1).

[18] Op. cit., pp. 400–425.

TABLE 1.

EXPERIMENTS AT 300° C. IN A CLOSED SYSTEM WITH HYDROSULPHURIC ACID.
Concentration: Saturated with H_2S at 25° C. Atmosphere: H_2S.

No.	Mineral.	Hours.	Results.		
			Material in Solution (Parts per Million).		Alteration Products.
			Iron	Gold	
5	Augite	167	5–10	—	Coating of FeS. Trace of opal.
32	Hornblende	175	1–5	None	Cryptocrystalline pyrite, traces black FeS, white "amorphous" mineral, anhydrite crystals.
15	Olivine	168	1–5	—	Coating of FeS locally.
50	Fayalite	174	50–100	5–10	Cryptocrystalline pyrite or marcasite.
25	Serpentine	168	10–50	None	Pyrite cubes. A black tarnish of FeS.
41	Antigorite	169	10–50	5–10	Black graphitic appearing deposit, FeS?
47	Garnet	171	100–200	1–5	Pyrite cubes in fine magnetite matrix. Crystals of magnetite and hematite. Chlorite plates, white chalcedony and opal. Locally quartz crystals.
38	Biotite	177	1–5	None	Pyrite cubes, plates of chlorite, white "amorphous" material, colorless tabular crystals, quartz?
38*a*	Biotite	398	1–5	None	Pyrite cubes, numerous etch figures. White "amorphous" product.
29	Chlorite	185	5–10	None	Trace of opal.
35	Chloritoid	183	10–50	None	Pyrite cubes, plates of chlorite. Colorless tabular crystals locally, quartz? "Amorphous" white deposit, nontronite?
14	Siderite	180	5–10	—	Pyrite, coating of FeS, some opal.
22	Magnetite	191	None	None	Pyrite cubes.
53	Hematite	195	1–5	5–10	Marcasite.
56	Orthoclase	168	None	None	White "amorphous" deposit. Kaolinite?

Augite was slightly attacked, but little iron was removed. The amount removed was precipitated as black ferrous sulphide; the precipitate was slightly magnetic. A trace of silica was in suspension in the solution.

Hornblende was covered with areas of crystalline pyrite. The crystals could not be resolved under the microscope, but the brass yellow color was apparent. Only a trace of iron remained in solution. Numerous tabular colorless crystals of anhydrite were seen on the hornblende. A small amount of a white "amorphous" mineral, associated with the sulphide is probably a mem-

ber of the kaolin group. It is "isotropic," white by reflected light, and has an index of 1.562.

Olivine was slightly altered. A little iron was found in solution. A colloidal ferrous sulphide was precipitated but in minor amounts.

Fayalite was covered with a cryptocrystalline deposit of sulphide. No other alteration product was observed. A large amount of iron was in solution. An equation representing the probable reaction is:

$$Fe_2SiO_4 + 2H_2S + 2S \rightarrow 2FeS_2 + SiO_2 + 2H_2O.$$

Antigorite was little altered. Its waxlike luster was somewhat dulled and a thin gray black graphitic-appearing colloidal deposit of FeS was left on the surface. A moderate amount of iron was in solution.

Garnet was extensively altered. The entire section was covered with a black finely crystalline deposit of magnetite. Excellent octahedral crystals of it were seen. Truncated rhombohedrons and striated hexagonal plates of hematite were locally prominent. In the fine magnetite matrix coarse to fine crystalline pyrite cubes were embedded, as well as a few colorless crystals suggesting quartz. These are tabular crystals, weakly birefringent, uniaxial, optically positive, and with refractive indices from 1.542 to 1.545. A fine white to bluish white deposit of probable chalcedony was prominent. This coating is white by reflected light; index of refraction approximately 1.540. A more cream colored "isotropic" mineral of amorphous appearance locally associated with it, with an index ranging from 1.440 to 1.460, suggests opal. A number of platy minerals were also found suggesting a chlorite. They are green to colorless minerals, showing faint pleochroism, moderate to low birefringence, low extinction angles, and refractive indices varying from 1.570 to 1.576 and 1.584 to 1.592. Some of the iron removed from the mineral remained in solution.

Biotite was extremely altered in places to a white flaky "amorphous" product. Even the least altered portion is almost trans-

parent, suggesting much of its iron had been leached. Most of the iron was precipitated as pyrite cubes and pyritohedrons. They were commonly arranged dendritically on the altered mica. The "amorphous" product is a cream to light brown colored mineral, pseudomorphous after biotite. It is "isotropic," non-pleochroic, white in reflected light, and has an index of refraction of 1.718. But for its index, it would be taken for a kaolin. An X-ray powder diagram of this material shows it to be crystalline, but no mineral with similar lines was found among more than a hundred films available for comparison. Minor amounts of a light green platy mineral, weakly pleochroic, weakly birefringent, optically positive, with an extinction angle of 0°, and with indices of refraction varying from 1.580 to 1.590, suggest one of the chlorite group.

Chlorite showed no alteration. A small amount of iron was found in solution, and traces of a white precipitate, probably colloidal silica.

Chloritoid was completely covered with large pyrite cubes; considerable iron remained in solution. Most of the alteration is composed of a white to bluish white "amorphous" product closely associated with the pyrite. Under the microscope it is an "isotropic" cream-colored aggregate, white under reflected light, with an index of 1.612. No optic figure was obtained even on large areas. It is insoluble in cold concentrated H_2SO_4, HNO_3, and HCl, but may have gelatinized in the latter. It may be nontronite.

A number of pale blue green plates, weakly birefringent and pleochroic, with an extinction angle of 0°–2°, and with indices varying from 1.580–1.586, suggest a chlorite. Another minor product noted is in pale pink tabular crystals, non-pleochroic, weakly birefringent, with low interference colors, and with indices of refraction varying from 1.544 to 1.549. The positive optic sign and uniaxial figure were taken from a poor interference figure, and thus are questionable, but suggest quartz.

Siderite was much altered. A little iron was in solution. The iron removed from the siderite was redeposited, for the most

part, as pyrite. Some "colloidal" ferrous sulphide was also noted. At the temperature of 300° C. some oxidation or decomposition of the H_2S must have occurred to liberate free sulphur. This, with the H_2S present, might form pyrite according to the following equation:

$$FeCO_3 + H_2S + S \rightarrow FeS_2 + CO_2 + H_2O.$$

Magnetite is entirely coated with fine pyrite cubes. The absence of iron in the solution suggests that the iron was precipitated as the sulphide as fast as it was removed from the mineral. The reaction probably occurred as follows:

$$Fe_3O_4 + 4H_2S + 2S \rightarrow 3FeS_2 + 4H_2O.$$

Hematite is largely altered to a sulphide showing distinctly tabular crystals; crystal form and color suggested marcasite, and this was proved by a polished surface examination, as the mineral is distinctly anisotropic. Only a trace of iron was in the solution, and a trace of gold was noted. The reaction is as follows:

$$Fe_2O_3 + 3H_2S + S \rightleftarrows 2FeS_2 + 3H_2O.$$

The formation of marcasite, rather than pyrite, is unusual and is not yet clear.

Orthoclase was covered with a thin white coating that is faintly anisotropic, non-pleochroic, and has indices varying from 1.560 to 1.565. This suggests a member of the kaolin group, probably kaolinite.

Discussion.

In summarizing the alterations produced with hydrosulphuric acid, a number of generalizations can be made.

This type of solution tends in the main toward the formation of pyrite where any iron is removed from the original mineral. This iron is probably removed in the ferrous state. The sulphide crystals form on top of the section and do not replace any constituent of the mineral. The one instance of the formation of marcasite rather than pyrite is not clear.

Silica is probably taken into solution in all cases, as would be expected at this temperature. Therefore, although no determination of it was made here, its presence in solution can be safely assumed. Locally the concentration was sufficient to deposit colloidal silica.

The oxidation occurring in a number of instances, such as the formation of magnetite and hematite from the garnet may be due to a partial decomposition of water.

EXPERIMENTS WITH SODIUM HYDROSULPHIDE SOLUTION.

A number of hydrothermal experiments were made at 300° C. and corresponding pressures with sodium hydrosulphide solutions (Table 2).

Augite became opaque and coated with a layer of cryptocrystalline pyrite. The crystal form could not be resolved, but the brass yellow color was apparent. The solution was colored yellow and had in suspension a small amount of black "colloidal" FeS. A light-colored precipitate was probably silica in the form of opal. Gold was noted in the more concentrated solution, and a quantitative determination gave 30 milligrams in 25 cc.

Hornblende showed only slight alteration. Several areas of cryptocrystalline pyrite were noted, but here again their minuteness makes them questionable. Several small colloidal aggregates of low index were seen, which are opal. A trace of iron was found in the solution, and a large amount of gold.

Olivine was coated with fine crystalline pyrite. Solution seemed to have been especially favorable along the grain boundaries of the olivine. The yellow solution showed only a trace of iron, but gave a pronounced reaction for gold.

Fayalite was extensively altered. Small pyrite cubes coated the entire section. An amorphous material with an index of refraction of 1.462 is fairly abundant, and is opal. The yellow solution contained no iron, but considerable gold. A small amount of opal was in suspension.

Serpentine was more opaque and locally was covered with py-

TABLE 2.

EXPERIMENTS AT 300° C. IN A CLOSED SYSTEM WITH SODIUM HYDROSULPHIDE SOLUTIONS.

Concentration: 0.83 molar Na_2S saturated with H_2S at 25° C. Atmosphere: H_2S.

No.	Mineral.	Hours.	Results.		
			Material in Solution (Parts per Million).		Alteration Products.
			Iron	Gold	
3	Augite	145	—	500–1,500	Cryptocrystalline pyrite, white opal.
31	Hornblende	209	1–5	1,500–2,500	Traces of cryptocrystalline pyrite, white "amorphous" material, opal?
20	Olivine	191	1–5	"	Pyrite cubes.
49	Fayalite	180	None	"	Pyrite cubes, white deposit of opal.
24	Serpentine	173	1–5	"	Pyrite, radiating aggregate, chalcedony?
40	Antigorite	170	100–200	"	Octahedrons of gold, aggregates of opal.
46	Garnet	184	None	"	Tabular colorless crystals, albite? FeS locally, traces of opal.
37	Biotite	173	1–5	"	Analcite in tetragonal trisoctahedrons, octahedrons of gold, traces of opal.
28	Chlorite	170	1–5	"	Cryptocrystalline pyrite?, trace of opal, acicular colorless mineral, chrysotile?
34	Chloritoid	167	1–3	"	Pyrite cubes, white coating of an "amorphous" mineral. Kaolinite?
13	Siderite	165	5–10	"	Pyrite cubes and gold octahedrons. Colorless mineral locally, quartz? Traces of FeS.
21	Magnetite	170	1–5	"	Pyrite cubes.
52	Hematite	206	1–5	"	Pyrite cubes.
55	Orthoclase	170	None	"	Analcite crystals, white deposit of opal, white "amorphous" aggregates, kaolinite?

rite. As the sulphide was mostly on the areas containing magnetite impurities, it is probable that most of the iron removed in solution came from them rather than from the serpentine. Fine white to yellow radiating aggregates were present locally. They are semi-brilliant by reflected light, almost isotropic, nonpleochroic, have parallel extinction, and an index of about 1.540. These constants suggest chalcedony. The yellow solution con-

tained only a trace of iron but much gold. Colloidal silica or opal was in suspension.

Antigorite was very slightly altered. Octahedral crystals of gold were sparingly distributed on the surface. Numerous patches of opal were seen. A large amount of iron, as well as of gold, was in the yellow solution. Opal was in suspension.

Garnet was slightly altered. Small areas of black FeS were observed, but none of pyrite. Some opal was seen. The major alteration was the formation of a large number of crystals, presumably albite. These are colorless tabular crystals of average dimensions between 0.01 mm. by 0.02 mm. with well developed prism and pinacoid faces. They have a low birefringence, an extinction angle of 0°–4°, and indices varying from 1.520 to 1.527, which are somewhat lower than in natural albite. The crystals were unaffected by concentrated HCl.

Biotite showed slight alteration. No sulphide was observed, but small octahedrons of gold were prominent locally. White, isotropic, aggregates of opal were scattered over the surface. The most interesting alteration product was a large number of excellent crystals of analcite. They are colorless and perfect tetragonal trisoctahedrons of an average size of from 0.01 to 0.03 mm. The crystals are partially sunk into the surface of the biotite, with about one-half their volume apparently below the surface; their index is 1.487. The yellow solution contained a trace of iron and a large quantity of gold.

Chlorite was very slightly altered. A few areas of a questionable cryptocrystalline sulphide were present. A number of small colorless balls composed of radiating spicules were noted. They are a faint yellow-green in color, anisotropic with a moderate birefringence, parallel extinction, and with indices varying from 1.545 to 1.555. These perhaps suggest chrysotile. The yellow solution contained only a trace of iron but much gold.

Chloritoid was extensively altered. A large number of small pyrite cubes was scattered over the entire section. In addition, a thin coating, approximately one-tenth the thickness of the section, of a cream-colored aggregate was on the surface. It is

isotropic or nearly so, dull in reflected light, and has an index of about 1.543. The low index may be due to submicroscopic included opal, and the mineral may be kaolinite. The yellow solution contained only a faint trace of iron, but much gold.

Siderite was coated with cubes of pyrite and octahedrons of gold. Minute amounts of a colorless prismatic mineral were seen. Its indices vary from 1.540 to 1.545, and other optical constants suggest that it is quartz derived from impurities in siderite. The yellow solution contained a trace of iron and much gold. Traces of black FeS were observed.

Magnetite was completely covered with pyrite cubes. The yellow solution contained only a trace of iron, but much gold. The reaction may be as follows:

$$Fe_3O_4 + 6NaHS + 2H_2O \rightarrow 3FeS_2 + 6NaOH + 2H_2.$$

Hematite was greatly altered, the entire surface being coated with fine pyrite cubes. The yellow solution contained only a trace of iron.

Orthoclase was considerably altered. No sulphides were noted, but opal coated the entire surface. A number of isotropic crystals with an index of refraction of 1.487 were identified as analcite. A few white "isotropic" aggregates with an index of refraction of 1.555 are tentatively classified as kaolinite. The low index obtained may have been due to some admixed opal. The solution was colorless. A large amount of gold was in solution.

Discussion.

This type of solution tends in the main toward the formation of pyrite where any iron is removed from the original mineral. The sulphide crystals lie on the surface and do not represent a replacement. They seem to form simultaneously with the removal of the iron, as in almost all cases very little if any iron remains in the solution. In the experiment with antigorite, however, no pyrite was precipitated, but a considerable amount of iron was removed in solution from the mineral. The writers can think of no plausible explanation for this single discrepancy.

Gold was consistently taken into solution. This confirms Ogryzlo's [19] statement that gold is removed as the double sulphide $Au_2S \cdot -Na_2S$. The solubility of this solution at a concentration of 0.83 Mol. over a period of 7 days at 300° C. is approximately 2.4 grams of gold per liter. This may be a much higher concentration than could be expected under natural conditions, but it does indicate the enormous quantities of the metal that could be transported by this agent.

The consistently deep etching of the gold seal of the bomb confirmed the solvent action of this solution. It was noticed that the seal was more brittle after contact with this type of solution than with the other two. The gold linings also were etched, necessitating their removal and refabrication at the end of the experiments. Magnetite was not formed in this solution. Ferrous sulphide was present only in traces in a few experiments but pyrite formed in most of them. This would indicate a rather complete oxidation of the NaHS, since pyrite does not seem to form in the absence of free sulphur.

Analcite is readily formed as a secondary mineral and has been synthesized by many investigators [20] in hydrothermal solutions.

In the experiment with garnet a sodic feldspar may have formed. In a perusal of geologic literature the writers found no case in which any had been synthesized in a manner similar to the present experiment.

EXPERIMENTS WITH SODIUM SULPHIDE SOLUTIONS.

A number of hydrothermal experiments were made at 300° C. and corresponding pressures with sodium sulphide solutions (Table 3).

Augite was coated with black "colloidal" FeS. Traces of colloidal masses suggesting opal were noted in the solution, which also contained finely suspended and colloidal ferrous sulphide. The finely crystalline sulphide exhibited slight magnetism. The solution had a bluish green color caused by the presence of the colloidal sulphide.

[19] Op. cit., p. 424.

[20] Clarke, F. W.: Op. cit., p. 373.

TABLE 3

EXPERIMENTS AT 300° C. IN A CLOSED SYSTEM WITH SODIUM SULPHIDE SOLUTIONS

Concentration: 0.83 molar. Atmosphere: H_2S.

No.	Mineral.	Hours.	Results.			
			Material in Solution (Parts per Million).		Material in Suspension.	Alteration Products.
			Iron.†	Gold.		
4	Augite	185	—	—	Colloidal FeS. Traces of opal.	None.
30	Hornblende	210	1–5	5–10	Traces of opal.	None.
19	Olivine	192	100–200	—	Traces of opal.	White fibers of chrysotile.
19a*	Olivine	365	1–5	1–5	Traces of very fine FeS.	Chrysotile. Results same as in Exp. 19. Deposits of FeS.
48	Fayalite	172	1–5	1–5	Traces of very fine FeS.	Green acmite needles, excellent hematite crystals.
26	Serpentine	168	—	—	Traces of very fine FeS.	White aggregates of chalcedony.
39	Antigorite	188	1–5	1–5	None.	Needles of chrysotile. Cryptocrystalline pyrite or scale of irridescent iron oxide in traces.
45	Garnet	172	1–5	1–5	Traces of very fine FeS.	Colorless needles, resembles chrysotile. X-ray diagram suggests a chlorite. Trace of FeS.
36	Biotite	188	1–5	1–5	None.	None.
27	Chlorite	173	—	1–5	Colloidal FeS.	Colorless acicular to tabular crystals, quartz or chrysotile.
33	Chloritoid	169	1–5	1–5	Very fine FeS.	Porous magnetite. Hematite crystals, white "amorphous" aggregate, kaolin group?
12	Siderite	166	—	—	Fine magnetite. Traces of opal.	Porous magnetite.
23	Magnetite	191	—	1–5	Colloidal FeS.	Largely oxidized to hematite.
51	Hematite	209	1–5	None	Traces of very fine FeS.	None.
54	Orthoclase	170	None	None	Traces of opal.	Analcite, excellent sulphur crystals. White "amorphous" aggregates, kaolin group? Acicular mineral, sericite or paragonite?

* Concentration = 1.33 molar.

† Where colloidal FeS was present, no estimate of iron in solution was possible.

Hornblende remained unaltered. Traces of colloidal silica or opal were in solution, and a trace of iron was found.

Olivine was greatly altered, being coated with a white, finely fibrous precipitate, of silky luster. Solution of the olivine occurred principally along its grain boundaries. An X-ray examination proved this material to be chrysotile. Much iron remained in the solution, and traces of white colloidal masses suggesting silica were observed. The solution, although clear, was colored deep yellow to brown.

A duplicate experiment with a somewhat stronger solution and double the experimental time produced a similar result. Observation showed approximately the same percentage of chrysotile and olivine as before. Here, however, only a trace of iron remained in solution. An almost colloidal black precipitate colored the solution a greenish brown. A few colorless crystals of quartz, lying on the surface of the chrysotile, were observed. They are anisotropic, of low birefringence, with an extinction angle of 0°, and with indices varying from 1.542 to 1.548.

Fayalite was somewhat altered. A thin acicular deposit of a colorless to white mineral coated most of the section. The acicular crystals are anisotropic, have high birefringence, an extinction angle of 0° to 6°, and indices varying from 1.785 to 1.805. Where the crystals were thickly matted on the section, the alteration showed a yellowish-green color. These constants suggest the soda pyroxene, acmite. Small hexagonal red plates of hematite were seen with the acmite needles. The solution contained a heavy fine black precipitate of ferrous sulphide. The filtrate contained only a trace of iron and of gold.

Serpentine was scarcely altered. Locally small amounts of yellow to white fibrous aggregates of chalcedony were seen. These are anisotropic, weakly birefringent, and have indices varying from 1.534 to 1.539.

Antigorite was slightly altered. A very small amount of apparently fine-grained pyrite was observed. No crystal form was distinguishable, but a dirty-yellow color was noted. Aggregates of colorless fine fibers were locally prominent. They are aniso-

tropic, moderately birefringent, with an extinction angle of 0°, and indices varying from 1.540 to 1.554. They seem to be chrysotile. The solution was light green in color and contained a trace of iron.

Garnet was greatly altered. The entire surface of the mineral was coated with a colorless to white acicular and fibrous deposit of silky luster. The alteration formed a thin mat of hairlike crystals on the garnet. The fibers are anisotropic, of low birefringence, have an extinction angle of 0°, and indices varying from 1.550 to 1.558. These constants and the general appearance point to chrysotile, but an X-ray diagram of this material does not agree with chrysotile. Search among hundreds of X-ray films of minerals and synthetic products was without result.

Biotite, at 300° C., showed no alteration. The solution had a slight greenish cast, and on analysis suggested a trace of iron. There was also a trace of gold in solution.

Chlorite was slightly altered. Locally small radiating aggregates of colorless needles were observed. They are anisotropic, weakly birefringent, have an extinction angle of 0°, and indices varying from 1.541 to 1.550. These may be quartz, but the acicular nature of the crystals also suggests chrysotile. The solution was colored a dark green by the large amount of colloidal ferrous sulphide.

Chloritoid was completely altered. Only a little black spongy material of magnetite remained of the section. Some crystals show a deep red internal reflection. These are probably hematite. Some colorless to white aggregates are almost isotropic, and have an index of approximately 1.540. The greenish-brown solution contained a large amount of non-magnetic ferrous sulphide in suspension. The filtered solution was nearly colorless and contained only a trace of iron.

Siderite was almost completely altered to finely crystalline porous magnetite. On the larger crystals the octahedral faces of the magnetite were easily distinguishable. The material is, of course, strongly magnetic. The solution was colored a bluish green by the finely suspended magnetite. Traces of white colloidal masses suggesting opal were seen.

Magnetite was partly oxidized to hematite. The solution carried a large amount of fine ferrous sulphide, that could only partially be removed by filtration. The reaction for this alteration might be written as follows:

$$Fe_3O_4 + Na_2S + H_2O \rightarrow Fe_2O_3 + FeS + 2NaOH.$$

Hematite showed no alteration products. The surface of several of the sections showed a slight amount of etching. A small amount of ferrous sulphide had been deposited on the seal. The solution contained a trace of iron but no gold.

Orthoclase was entirely coated with a thin white deposit. It was composed principally of three products. The first was an aggregate of colorless acicular to fibrous crystals. These are anisotropic, moderately birefringent, have an extinction angle of about 0°, a positive sign of elongation, and indices varying from 1.576 to 1.585. One of the micas might best fit these constants. The second product is isotropic, in irregular masses, and has an index of refraction of 1.490, which suggests analcite. A white "amorphous" aggregate was the third alteration product. It could not be identified.

Many bluntly terminated yellow prisms with indices of over 2.00 were seen locally. They are sulphur crystals. The oxidation of sodium sulphide in the absence of any iron, evidently caused a precipitation of free sulphur. The solution contained no gold.

Discussion.

Sodium sulphide solution does not cause pyrite to form.

Ferrous sulphide was found in almost all cases where any iron was removed in solution from the mineral. The amount in some instances was small, but in the majority of cases a heavy precipitate occurred. The question might be asked why ferrous sulphide precipitates are formed in these solutions when it was stated previously, that Na_2S is unstable in the presence of silica and, therefore, would not form soluble double sulphides with iron. The answer may be threefold:

1. Although the solubility product of $FeS \cdot Na_2S$ is low, it is sufficient to cause the intermediate reaction necessary to change more soluble iron silicate to a less soluble iron sulphide.

2. The silicates used may have a smaller solubility product in these solutions than the silica of silica tubes and pyrex glass, which were used in the experiments in which the reaction previously mentioned took place.

3. The amount of iron silicate used, especially the amount of surface exposed, was small compared with the amount of solution in the bombs. In pyrex and silica tubes the surface is very much larger in comparison.

The synthesis of chrysotile is of unusual interest. To the writers' knowledge, no previous investigator has obtained it in this manner. Chrysotile appears to form not only from olivine, but from other high magnesium bearing silicates. Although that obtained from olivine was definitely proven, the optical constants of some of the other alteration products are such to suggest chrysotile.

The formation of acmite from fayalite is also of interest. Although it has been synthesized by many investigators by a fusion of its various constituents, no one seems to have produced it in hydrothermal solutions.

Sodium sulphide solutions have no solvent action on gold. Small traces were observed in a number of experiments, but these seem to be due to a slight solution of H_2S (used to displace the air in the bomb) in the Na_2S forming NaHS.

The absence of any alteration of the hematite seems to indicate that alterations are largely dependent upon oxidation. Where the metallic ions of the minerals have already their highest valence, no further change takes place.

CONCLUSIONS.

Hydrothermal experiments on thin slices of a number of minerals show that many minerals will alter to a greater or lesser extent in solutions of H_2S, NaHS, or Na_2S at 300° C. and corresponding pressures.

Minerals of hydrothermal origin are least affected by further treatment with these solutions. This applies to such minerals as chlorite and serpentine.

Oxidation seems to play a prominent role in the alteration of minerals with the solutions used in this study. In the solutions of H_2S and NaHS, the $S^=$ ion was evidently oxidized to free sulphur. In the presence of this, or any polysulphides formed, the iron removed in solution from the original mineral forms iron disulphides.

In Na_2S solutions, oxidation seems to be even more pronounced, forming oxides of iron in many instances with the iron removed from the original mineral. Even a mineral difficult to oxidize as magnetite was converted into hematite.

Hematite in excellent tabular hexagonal plates was formed in a number of instances on iron minerals in NaHS and Na_2S solutions.

Magnetite was formed in several instances by H_2S and Na_2S solutions.

Silica was taken into solution with all three types of solutions. Where precipitated, it was generally in the form of opal, and occasionally as chalcedony or quartz.

Pyrite forms easily with solutions of NaHS and H_2S but not in those of Na_2S.

Excellent crystals of marcasite were formed on hematite in H_2S solution.

Ferrous sulphide, either finely crystalline, colloidal, or both in size, was readily formed in solutions of Na_2S, but not in those of NaHS or H_2S.

Gold is readily soluble in solutions of NaHS, but not in those of Na_2S or H_2S.

Analcite was formed from both NaHS and Na_2S solutions acting on various minerals.

Chrysotile was formed from a number of high magnesium silicates in Na_2S solutions.

The soda pyroxene, acmite, was formed by an Na_2S solution acting on fayalite.

Chlorite was formed with a number of minerals in the presence of an H_2S solution.

A mineral tentatively classed as "albite" was formed from an NaHS solution acting on garnet.

A mineral tentatively classed as "sericite" or "paragonite" was formed on orthoclase with an Na_2S solution.

Anhydrite formed on hornblende in an H_2S solution.

Excellent crystals of sulphur were precipitated on orthoclase from an Na_2S solution.

DEPT. OF GEOLOGY AND MINERALOGY,
UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.,
March 9, 1939.

MEASUREMENTS IN BLOCK DIAGRAMS.

RONALD L. IVES.

ABSTRACT.

Measurements of angles and distances in non-perspective block diagrams, usually done by the complicated methods of descriptive geometry, may be facilitated and the accuracy increased by the use of trigonometric methods. Correction formulae, their derivation, and a correction table for use with isometric block diagrams, are here presented.

INTRODUCTION.

ANGLES in non-perspective block diagrams of most types, and distances in directions not parallel to certain coordinates, cannot be compared either with each other or with regular standards except under special conditions.

Methods of determining true values of angles and distances in block diagrams of certain types, by the use of descriptive geometry, have been described by Lobeck.[1] These, although theoretically correct, are time-consuming, and adequately accurate only when skillfully used. Where many measurements must be made on a single figure, the use of superposed graphical methods soon produces a highly confusing aggregate of construction lines covering the figure and the paper for some distance around it.

Trigonometric methods, in general, are slightly slower than those of descriptive geometry where only a single measurement is to be made on a figure, but greatly expedite the work when many lines and angles must be scaled from a single figure, or from several figures in the same projection. With isometric block diagrams, when the accompanying correction table (Table 1) is used, trigonometric methods are considerably faster than the usual graphical methods, even for a single measurement.

[1] Lobeck, A. K.: Block Diagrams. John Wiley and Sons, New York, 1924.

ISOMETRIC BLOCK DIAGRAMS.

Because of the ease with which they may be constructed, isometric block diagrams are much used as geologic illustrations.[1, 2] In these figures, equal distances along or parallel to any coordinate are equal. In Fig. 1, an isometric representation of a rectangular

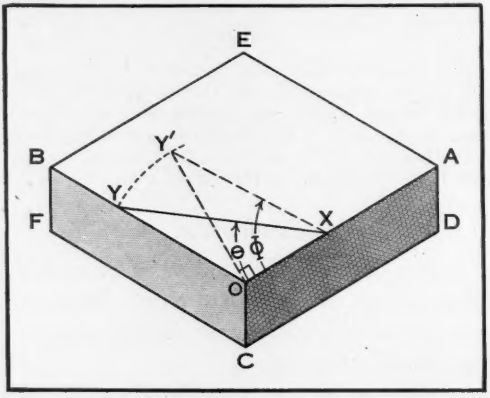

FIG. 1. Graphical correction of length and angle in isometric block diagram.

parallelopiped, the three rectangular faces are shown as rhomboids, the angles at and opposite the intersection of the coordinates *OA*, *OB*, and *OC*, are expanded from 90 to 120 degrees, while the two remaining angles in each rectangle have been "squeezed down" from 90 to 60 degrees. As the lengths of the sides of the rectangular faces have not been changed by the projection, distances measured along or parallel to them are still "true" despite the distortion. In an isometric block diagram, any line on a plane, not drawn parallel to a coordinate, eventually intersects the other two planes, forming, with the traces of the planes intersected, a triangle. As the distances from the "origin" to the intersections are "true," and the true angle between the traces of the planes is 90 degrees, all other parts of the triangle may be calculated. The construction

[2] Johnston, W. D., Jr., and Nolan, T. B.: Isometric block diagrams in mining geology. ECON. GEOL., 32: 550–569, 1937.

necessary for determining a true length and angle graphically is shown on the upper plane ($OAEB$) in Fig. 1. From trigonometric consideration of this figure the correction formulæ are derived.

Derivation of Formulæ.

Construction—(Fig. 1).—Rotate OY to a new position OY', in which angle $Y'OX$ is 90 degrees. This corrects distortion, putting points Y' and X in their true relation. $OY' = OY$.

Connect X and Y'. The distance XY' represents the true length of XY. The angle $OXY'(\phi)$ is the true angle represented by $OXY(\theta)$.

Derivation.—θ is the measured angle. ϕ is the corresponding true angle.

(*a*) $$OY' = OY,$$

$$\frac{OY'}{OX} = \tan\phi,$$

$$OX = OY\cot\phi;$$

(b) $$\frac{OX}{\sin(OYX)} = \frac{OY}{\sin\theta} \quad \text{(law of sines)},$$

$$OX = \frac{OY\sin(OYX)}{\sin\theta};$$

equating (*a*) and (*b*),

$$\cot\phi = \frac{\sin(OYX)}{\sin\theta}$$

for a 120 degree figure, $(OYX) = (60° - \theta)$,

$$\cot\phi = \frac{\frac{1}{2}\sqrt{3}\cos\theta - \frac{1}{2}\sin\theta}{\sin\theta};$$

(1) $$\cot\phi = \tfrac{1}{2}\sqrt{3}\cot\theta - \tfrac{1}{2}.$$

$$F = \frac{\text{true distance}}{\text{measured distance}} = \frac{XY'}{XY};$$

(*c*) $$XY' = OY\csc\phi;$$

(*d*) $$\frac{XY}{\sin(XOY)} = \frac{OY}{\sin\theta},$$

$$XY = \frac{OY\sin(XOY)}{\sin\theta};$$

(*c*/*d*) $$F = \frac{XY'}{XY} = \frac{\csc\phi\sin\theta}{\sin(XOY)}$$

for a 120 degree figure, $\sin(XOY)$ is $\frac{1}{2}\sqrt{3}$.

(2) $$F = \frac{2\sin\theta}{\sqrt{3}\sin\phi}.$$

TABLE 1

θ	ϕ	F	θ	ϕ	F	θ	ϕ	F
0°	0° 00′	1.000	45°	69° 54′	0.869	90°	116° 34′	1.290
1°	1° 10′	0.990	46°	71° 25′	0.876	91°	117° 15′	1.298
2°	2° 21′	0.980	47°	72° 54′	0.883	92°	117° 56′	1.306
3°	3° 34′	0.970	48°	74° 22′	0.891	93°	118° 37′	1.314
4°	4° 49′	0.961	49°	75° 49′	0.899	94°	119° 17′	1.321
5°	6° 05′	0.951	50°	77° 14′	0.907	95°	119° 56′	1.327
6°	7° 22′	0.942	51°	78° 37′	0.915	96°	120° 35′	1.334
7°	8° 40′	0.933	52°	79° 59′	0.924	97°	121° 14′	1.340
8°	10° 01′	0.924	53°	81° 19′	0.933	98°	121° 52′	1.346
9°	11° 23′	0.915	54°	82° 38′	0.942	99°	122° 30′	1.352
10°	12° 46′	0.907	55°	83° 55′	0.951	100°	123° 08′	1.358
11°	14° 11′	0.899	56°	85° 11′	0.961	101°	123° 45′	1.363
12°	15° 38′	0.891	57°	86° 26′	0.970	102°	124° 23′	1.368
13°	17° 06′	0.883	58°	87° 39′	0.980	103°	124° 59′	1.373
14°	18° 35′	0.876	59°	88° 50′	0.990	104°	125° 36′	1.377
15°	20° 06′	0.869	60°	90° 00′	1.000	105°	126° 12′	1.382
16°	21° 38′	0.863	61°	91° 09′	1.010	106°	126° 49′	1.386
17°	23° 12′	0.857	62°	92° 16′	1.020	107°	127° 25′	1.390
18°	24° 47′	0.851	63°	93° 22′	1.031	108°	128° 00′	1.394
19°	26° 23′	0.846	64°	94° 26′	1.041	109°	128° 36′	1.397
20°	28° 01′	0.841	65°	95° 29′	1.051	110°	129° 11′	1.400
21°	29° 39′	0.837	66°	96° 31′	1.062	111°	129° 47′	1.403
22°	31° 19′	0.832	67°	97° 33′	1.072	112°	130° 22′	1.405
23°	33° 00′	0.828	68°	98° 32′	1.083	113°	130° 57′	1.407
24°	34° 41′	0.825	69°	99° 30′	1.093	114°	131° 32′	1.409
25°	36° 36′	0.823	70°	100° 28′	1.103	115°	132° 07′	1.411
26°	38° 06′	0.821	71°	101° 25′	1.114	116°	132° 41′	1.412
27°	39° 49′	0.819	72°	102° 20′	1.124	117°	133° 16′	1.413
28°	41° 32′	0.818	73°	103° 14′	1.134	118°	133° 50′	1.413
29°	43° 16′	0.817	74°	104° 08′	1.145	119°	134° 25′	1.414
30°	45° 00′	0.816	75°	105° 00′	1.155	120°	135° 00′	1.414
31°	46° 44′	0.817	76°	105° 50′	1.165	121°	135° 35′	1.414
32°	48° 28′	0.818	77°	106° 42′	1.175	122°	136° 09′	1.413
33°	50° 11′	0.819	78°	107° 32′	1.185	123°	136° 44′	1.413
34°	51° 54′	0.821	79°	108° 21′	1.194	124°	137° 19′	1.412
35°	53° 57′	0.823	80°	109° 09′	1.204	125°	137° 54′	1.411
36°	55° 19′	0.825	81°	109° 57′	1.213	126°	138° 29′	1.409
37°	57° 00′	0.828	82°	110° 43′	1.223	127°	139° 31′	1.407
38°	58° 41′	0.832	83°	111° 29′	1.232	128°	139° 38′	1.405
39°	60° 20′	0.836	84°	112° 15′	1.241	129°	140° 14′	1.403
40°	61° 59′	0.841	85°	112° 59′	1.250	130°	140° 49′	1.400
41°	63° 36′	0.846	86°	113° 43′	1.258	131°	141° 24′	1.397
42°	65° 13′	0.851	87°	114° 27′	1.267	132°	142° 00′	1.394
43°	66° 48′	0.857	88°	115° 09′	1.275	133°	142° 36′	1.390
44°	68° 21′	0.863	89°	115° 52′	1.283	134°	143° 12′	1.386

TABLE 1—*Continued*

θ	ϕ	F	θ	ϕ	F	θ	ϕ	F
135°	143° 48′	1.382	150°	153° 23′	1.291	165°	165° 00′	1.155
136°	144° 24′	1.378	151°	154° 08′	1.283	166°	165° 52′	1.145
137°	145° 01′	1.373	152°	154° 50′	1.275	167°	166° 64′	1.135
138°	145° 38′	1.368	153°	155° 33′	1.266	168°	167° 40′	1.124
139°	146° 15′	1.363	154°	156° 17′	1.258	169°	168° 36′	1.113
140°	146° 52′	1.357	155°	157° 01′	1.249	170°	169° 32′	1.103
141°	147° 30′	1.352	156°	157° 45′	1.240	171°	170° 29′	1.093
142°	148° 08′	1.346	157°	158° 30′	1.232	172°	171° 28′	1.083
143°	148° 46′	1.340	158°	159° 16′	1.223	173°	172° 28′	1.072
144°	149° 25′	1.334	159°	160° 03′	1.213	174°	173° 28′	1.061
145°	150° 04′	1.327	160°	160° 51′	1.204	175°	174° 30′	1.051
146°	150° 43′	1.320	161°	161° 39′	1.194	176°	175° 34′	1.041
147°	151° 23′	1.313	162°	162° 28′	1.185	177°	176° 38′	1.031
148°	152° 04′	1.306	163°	163° 18′	1.175	178°	177° 44′	1.020
149°	152° 45′	1.299	164°	164° 09′	1.165	179°	178° 51′	1.010
						180°	180° 00′	1.000

Correction Table.—From the formulæ (1) and (2) above, the accompanying correction table (Table 1) was calculated. This table was designed for use with a protractor, dividers and slide rule. Values of θ are exact, corresponding values of ϕ are in error not more than 30″, and corresponding F values are accurate to within .001. Where higher accuracy is desired, correction factors may be calculated from the formulæ (1) and (2).

It will be noted, in this table, that the F values are symmetrical about the lines $\theta = 30°$ and $\theta = 120°$, and that they are the same for an angle and its "isometric complement" ($60° - \theta$ or $120° - \theta$, depending upon the value of θ). In an isometric block diagram, when two angles are "isometric complements," their true values are true complements, and their correction factors (F values) are equal. This axiom may be verified either graphically or trigonometrically.

Use of Correction Table.

The accompanying correction table was designed for use in finding true angles and distances in isometric block diagrams, but may be "worked backwards," with little difficulty to find distorted values. Interpolations may be made in the usual manner, and are

subject to about the same errors as interpolations in any other simple trigonometric table. A brief outline of the methods to be followed in correcting measurements in isometric block diagrams, by the use of the table, follows.

To Determine the True Value of an Angle (Fig. 1).—Measure the angle in the diagram, using the directions OXY or OYX in Fig. 1. Read this angle in the θ column of the correction table. Opposite this, in the ϕ column, read the true value of the angle.

To Determine the "True" Length of a Line (Fig. 1).—The "true" length of a line in an isometric block diagram cannot be found until the angle between that line and a coordinate is known. Measure the angle between the line (extended if necessary) and a coordinate (use directions OXY and OYX as above). Find this angle in the θ column of the correction table. Opposite this, in the F column, read the correction factor, by which any scaled length along this line must be multiplied to secure the "true" length. A slide rule will be found convenient and sufficiently accurate for these calculations.

To Determine the True Angle Between Two Lines (Fig. 2).—When two lines on an isometric surface intersect, the true angle between them cannot be measured directly, nor can its value be found by any simple correction. The true angles between the intersecting lines and a coordinate, however, can be found without difficulty and as the angle of intersection is the third angle of a triangle, its true value can be computed.

In Fig. 2, the lines GH and LM intersect at K, the angle of intersection being β. The true value of β may be found by several methods:

A. Extend AO and HG until they intersect. Measure the exterior intersection angle, θ, and find its true value from the correction table.

Find the true value of Δ from the correction table.

The true value of β will be the difference between the true value of θ and that of Δ.

B. Draw $G'H'$ parallel to GH. Measure its angle of intersection with $OA(\theta')$ and find the true value of this angle from the correction table.

Find the true value of Δ from the correction table.

The true value of β will be the difference between the true value of θ' and that of Δ.

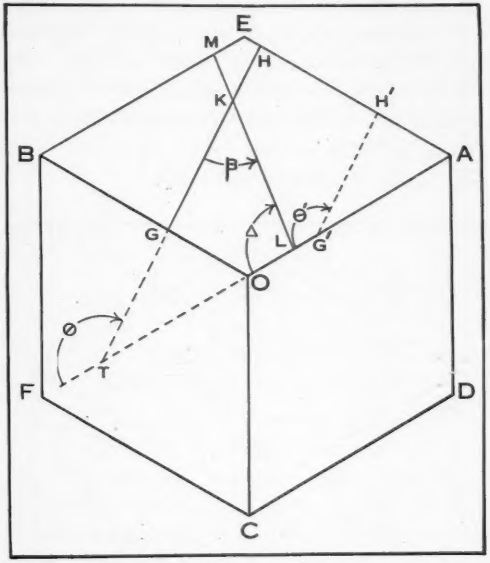

FIG. 2. Determination of angle between two lines.

C. This method requires one more simple calculation than either of the two previously outlined, but needs no construction lines.

Measure the angle *BGH*. To *BGH* add 60°. The result equals θ. Find the true value of $(BGH + 60°)$ from the correction table. Find the true value of Δ from the correction table. The true value of β will be the difference between the true value of $(BGH + 60°)$ and that of Δ.

Other Computations.—Numerous other computations are at times necessary in connection with isometric block diagrams. These, in general, are best made by converting the angles and distances in the figure into true angles and distances, and then computing the desired values by trigonometry or analytic geometry. In a few instances, shorter methods are available.

"Short Cut" Methods.

By taking advantage of the fact that distances along lines parallel to any coordinate of an isometric block diagram are "true," and that the true angle of intersection of two coordinates, or lines parallel to coordinates, is a right angle, many computations with these diagrams may be shortened. Most of these "short cuts" make use of an "isometric perpendicular"—a line drawn parallel to one coordinate of a surface and intersecting the other coordinate of that surface, or a line parallel to it. In Fig. 3, the lines *QQ'*, *RR'*, *SS'*, etc., are isometric perpendiculars.

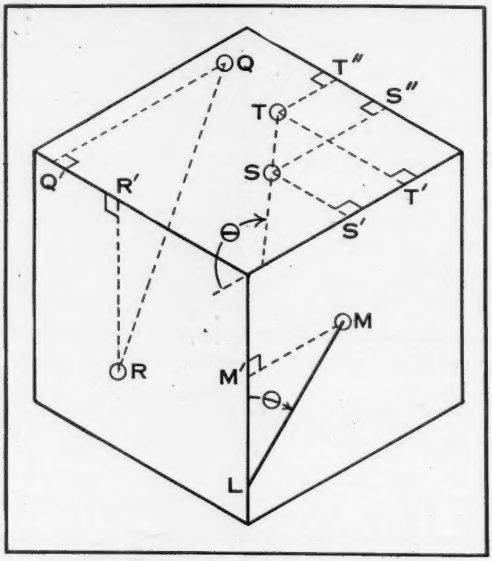

FIG. 3. Construction for "short cut" computations.

To Find the "True" Distance Between Two Points on the Same Surface (Fig. 3, Points S and T).

A. Draw a line through the points, extending far enough to intersect a coordinate.

Determine the angle (θ) between this line and the coordinate.

From the table (Table 1) determine the correction factor (F) corresponding to this angle.

Multiply the scaled distance ST by this factor. The result is the "true" length ST.

B. From S and T drop isometric perpendiculars S' and T' to one coordinate bounding the surface, or to a line parallel to a coordinate. Drop similar perpendiculars S'' and T'' to the other coordinate, or to a line parallel to it. Distances $S'T'$ and $S''T''$ are "true." The true angle of intersection of the coordinates is a right angle.

The true distance ST is $\sqrt{(S'T')^2 + (S''T'')^2}$.

Also,

$$\tan (180° - \theta) = \tan \theta = \frac{T''S''}{T'S'}.$$

To Find the "True" Distance Between Two Points Not on the Same Surface (Fig. 3, Points Q and R).

From Q and R drop isometric perpendiculars QQ' and RR' to the coordinate separating the surfaces containing Q and R. (Distances QQ', $Q'R'$, and RR' are true, being measured parallel to coordinates; true values of angles $R'Q'Q$ and $RR'Q'$ are 90°.)

True distance QR is $\sqrt{(QQ')^2 + (Q'R')^2 + (RR')^2}$.

To Find the True Value of an Angle (Fig. 3, Angle MLM').

Drop an isometric perpendicular MM'.

Tan ϕ (true value of θ) is $\frac{MM'}{LM}$.

To Find a "True" Distance (Fig. 3, ML).

Drop an isometric perpendicular MM'.

Scale MM' and LM. These distances, being along or parallel to coordinates, are "true." The true value of angle $MM'L$ is 90°.

$ML = \sqrt{(LM')^2 + (MM')^2}$.

NON-ISOMETRIC, NON-PERSPECTIVE FIGURES.

An infinite number of non-isometric, non-perspective representations of the same three-dimensional data are possible, with the

coordinates of the figures making various angles with each other, and having various linear relations. It is not possible to compute a correction table covering all possible non-isometric, non-perspective projections, nor can simple all-inclusive formulæ be derived. Each special projection must be taken as a separate case. In general, the formulæ are best worked out by trigonometric consideration of the construction necessary for determining true angles and distances by descriptive geometry.

The method by which correction formulæ for one non-isometric projection are derived will be presented in some detail. From this, by use of the same general method, other formulæ, for other projections, may be derived.

In Fig. 4, a rectangular parallelopiped is shown in a projection in which the X and Y axes are drawn respectively horizontal and vertical, while the Z axis bisects the angle between the other two.

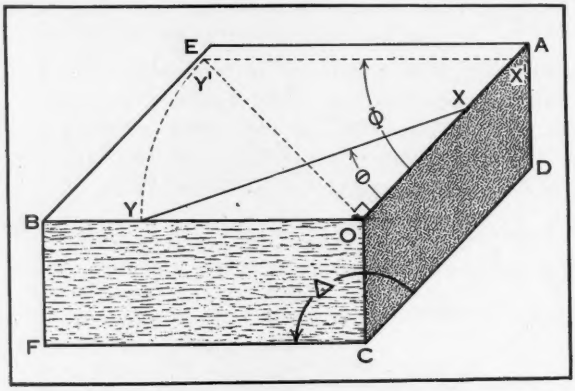

FIG. 4. Non-isometric, non-perspective figure.

Distances in the X and Y directions are "true"; those in the Z direction have been reduced, to provide more foreshortening. Hence, any distance along the Z axis, such as OX, must be multiplied by a correction factor, K, to be "true."

All angles and distances on the front plane, $OBFC$, of Fig. 4 are "as scaled." Angles and distances on the other two planes

need considerable correction before their true values can be determined. In deriving the formulæ for correcting angles and distances not on the front plane of Fig. 4, the triangle OYX in that figure will be used.

Derivation of Formulæ.

Construction (Fig. 4).—Rotate OY to a new position OY', in which the angle $Y'OX$ is a right angle. This corrects for distortion in the projection. $OY = OY'$.

Scale OX. Multiply it by the foreshortening factor K. From O measure off the distance $K(OX)$ along OA. This distance is OX' in the figure. This corrects for foreshortening in the Z direction.

Connect X' and Y'. The distance $X'Y'$ represents the true length of XY. The angle $OX'Y'(\phi)$ is the true angle represented by $OXY(\theta)$.

Derivation.—θ is the measured angle. ϕ is the corresponding true angle.

(*e*) $$OY = OY', \qquad OX' = K(OX).$$

$$\frac{OY'}{OX'} = \tan\phi,$$

$$OX = \frac{OY\cot\phi}{K}.$$

(*f*) $$\frac{OX}{\sin(OYX)} = \frac{OY}{\sin\theta},$$

$$OX = \frac{OY\sin(OYX)}{\sin\theta};$$

equating (*e*) and (*f*),

$$\frac{\cot\phi}{K} = \frac{\sin(OYX)}{\sin\theta},$$

$$\cot\phi = K\frac{\sin(OYX)}{\sin\theta},$$

$$\sin(OYX) = \sin 180 - (\Delta + \theta) = \sin(\Delta + \theta),$$

$$\cot\phi = K\frac{\sin\Delta\cos\theta + \sin\theta\cos\Delta}{\sin\theta};$$

(3) $$\cot\phi = K(\sin\Delta\cot\theta + \cos\Delta);$$

(4) $$F = \frac{\text{scaled distance}}{\text{true distance}} = \frac{X'Y'}{XY} = \csc\Delta\frac{\sin\theta}{\sin\phi}.$$

This derivation is identical with that for (2) except that $X'Y'$ is substituted for XY'.

It will be noted that these formulæ (3 and 4) apply to all figures in which the front plane is a true representation, while the top and side planes are distorted. Where equal distances along all three axes are equal in the figure, $K = 1$.

SUMMARY.

Computations in connection with non-perspective block diagrams, regardless of the projection, may be simplified by the use of trigonometry in conjunction with descriptive geometry.

With isometric block diagrams, work can be expedited by the use of the accompanying correction table.

Formulæ for correcting measured distances and angles in any block diagram can be rapidly worked out by use of methods here outlined.

If conditions warrant, correction tables for any projection may be compiled from the formulæ. Such compilation, requiring several days of intense work (unless a computing machine is available), is not justified unless one projection is to be used many times.

None of the formulæ here given can be applied without much modification to perspective block diagrams. Methods of dealing with perspective figures have recently been described.[3]

ACKNOWLEDGMENTS.

The writer is indebted to Drs. W. D. Johnston, Jr., and J. B. Mertie, Jr., both of the U. S. Geological Survey, and to Dr. George H. Light, of the University of Colorado, for many helpful discussions in connection with this work.

BOULDER, COLORADO,
March 9, 1939.

[3] Secrist, M. H.: Perspective block diagrams. ECON. GEOL., 31: 867–880, 1936.

THE OOLITIC LIMESTONE DEPOSITS OF FRANKLIN COUNTY, ALABAMA.

WALTER B. JONES.*

ABSTRACT.

For three-quarters of a century, Oolitic limestone has been quarried in the Franklin County, Alabama, district, for building purposes. The stone occurs in two horizons within the Bangor limestone formation of Subcarboniferous age. At present, the commercial stone appears to be confined to Franklin County within a belt some fifteen miles in length, centering around Russellville.

INTRODUCTION.

THE presence of oolitic limestone in the vicinity of Russellville was recognized 80 years ago by Michael Tuomey,[1] and specimens collected by Tuomey were analyzed and described by Mallet [2] as having a "general appearance strikingly like that of the English oolite."

Apparently the first actual quarrying was by T. L. Fossick between 1875 and 1880. Fossick supplied buttress caps, steps, and window sills for the new buildings erected at the University of Alabama between 1878 and 1885, over the ruins of the buildings destroyed during the Civil War. Since that time the limestone from the Franklin County deposits has found wide use in the United States and Canada.

LOCATION AND TOPOGRAPHY.

Although practically all of the Mississippian limestones throughout the Tennessee Valley in Alabama carry some oolitic layers and lenses, it is thought that the really commercial oolitic stone is confined to Franklin County. Deposits of oolitic lime-

* Presented before the joint meeting of the S. E. G. and the A. I. M. E., Knoxville, Tenn., Oct. 6, 1938.

1 Tuomey, Michael: Geology of Alabama, 1858, p. 20.

2 Mallet, J. W.: Tuomey's Geology of Alabama, 1858, p. 184.

stone adapted to dimension stone appear to be confined to the western portion of the Moulton-Russellville Valley, and most particularly from Aday to Rockwood (Fig. 1). The valley is essentially flat, although the underlying rocks dip slightly southwest, and is floored with residual limestone soils that are very fertile.

Practically all of the valley drains west, through the lowlands between Tuscumbia or Little Mountain to the north, and the rim

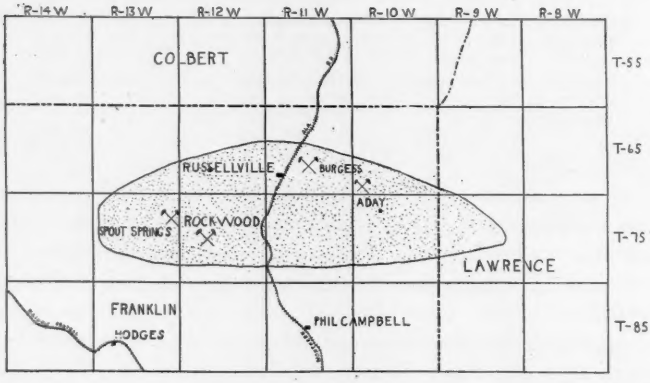

FIG. 1. Sketch map showing the area of building limestone (oolitic) deposits in Alabama, and the most important quarries. Shaded area outlines absolute limit of building limestone in the district.

of the plateau or Sand Mountain to the south. Most of the valley floor is two to three hundred feet below the rim of Sand Mountain and in some places the valley is dotted with low hills and promontories, which range up to 200 feet above the valley proper.

GEOLOGY.

Moulton Valley is made up entirely of Bangor limestone of Mississippian age, underlain by the Hartselle sandstone that caps Tuscumbia Mountain to the north and dips southwestward, and is overlain by the basal Pottsville formation of Pennsylvanian age.

To the west the clays and gravels of the Tuscaloosa formation of Cretaceous age form a blanket over Hartselle, Bangor and Coal Measures alike. Much gravel is to be found in the vicinity of the limestone quarries. It is in the Bangor limestone that all of the commercial oolitic stone has been found. It is also interesting that the weathering of these limestones forms the extensive deposits of brown iron ore of the Russellville district. The best brown iron ore deposits and the best oolitic limestone deposits occur in the same region, within a few miles of each other.

The beds have not been subjected to any noticeable disturbances; both folding and faulting are unknown. The Bangor is quite fossiliferous, crinoid stems, bryozoans, blastoids and corals being particularly abundant, especially the bryozoan *Archimedes* and the blastoid *Pentremites*. There is a great variety of corals, and some layers appear to be made up completely of crinoid stems. A general section is as follows:

Top	Cretaceous blanket of gravel, sand and clays.
	Coal Measures sandstones and shales, forming the cap rock for Sand Mountain.
	Bangor Limestone
200′	Blue fossiliferous limestone, hard to flinty, massive-bedded; some coral reefs.
0–40′	Burgess oolite, type locality at Burgess quarry, 2 miles east of Russellville. Variable in thickness and physical properties.
100′	Blue, slightly fossiliferous limestone. Also carries residual brown ore mined in Russellville district.
0–55′	Rockwood oolite, type locality, Rockwood; 55′ thick. More extensive and much less variable than the Burgess oolite; beds at top and bottom highly fossiliferous.
0–50′	Spout Spring oolite, massive-bedded, hard, uniformly oolitic, gray, suitable for use as marble.
100′	Blue to gray flinty limestone and dolomites, with several thin layers of shale. Abundantly fossiliferous, thin- to thick-bedded, rarely massive-bedded.
	Hartselle Sandstone
300′	Sandstone, found in Little Mountain.
	Golconda, Cypress, Gasper, etc.
140′	Limestones, cherts, and calcareous shales. Exposed on Tennessee Valley slopes to the northward.

The oolitic limestone members are in the form of lenses; it will be assumed that all of the oolitic beds belong to the horizons indicated, although this is not certain.

Burgess Oolite.—The Burgess oolite has its greatest thickness and type locality at the Burgess quarry, some two miles east of Russellville. The quarry was opened on the southeast slope, near the top of a rather high hill. The lower slopes of the hill had been almost entirely surrounded with brown iron ore workings and there is still a good deal of ore in the small areas of residual soils that yet remain. The Burgess quarry was not operated for any great length of time, because it produced a large proportion of unsound blocks, and because of inaccessibility of the area. From such evidence as lime sinks, heavy dirt seams and the like, it is thought that the quarry was poorly located, and that the eastern slopes of the hill might have been much better.

At the Burgess quarry, the stone is light gray, uniformly oolitic, and of rather even texture. The total thickness of the Burgess oolite is 40 feet, the lower 30 of which was actually quarried. The top 10 feet was considered too hard for sawing, although the texture of the stone appears to be satisfactory. The lower few feet at the Burgess quarry contain an abundance of tiny facets of calcite, and most of the solution channels are lined with onyx.

Because of its comparatively small outcrop area in the vicinity of the Burgess quarry, it is difficult to estimate how much oolitic stone may remain there. It was traced for some 200 yards to the eastward to where residual soils and vegetation completely cover it. There seem to be a generally thin but persistent oolite at the horizon of the Burgess member. Nowhere else except at the Burgess quarry was the member thick enough to be of commercial importance for dimension stone.

Rockwood Oolite.—This is by far the more important of the three oolitic members recognized, since it occurs over a relatively large area. It is at least 20 feet thick from Newburg to Belgreen, a distance of almost 20 miles, and in some places the lens of oolitic stone attains a width of at least three miles. Apparently, the maximum thickness of the Rockwood member is at the type

locality of Rockwood, where it is at least 55 feet thick. Not all of that thickness can be utilized for dimension stone, for the upper layer, from 0 to 15 feet thick, is too hard.

The Rockwood oolite fringes hills and ranges on both sides of Cedar Creek and several quarries are located in the general vicinity of Rockwood. It was in this region that the first oolitic limestone was produced in Alabama, by T. L. Fossick, as already mentioned. Near Fossick's old quarry is one of the largest quarries in the district. The Rockwood oolite has been fairly definitely identified at some 20 localities between the Aday quarry at Waco, westward to the Cretaceous blanket. It is uncertain whether or not the various outcrops represent a continuous lens or a series of lenses at the same horizon. It does appear, however, that the general horizon is the same over all of this area. The member is rather uniformly oolitic, although the possibility of finding suitable quarry sites is naturally limited.

East of Newburg the member thins out and the light gray color changes to a dark color, caused by the impregnation of the rock with asphaltum. It is not believed that commercial quarries will ever be located very far east of Waco. The commercial stone, therefore, is confined to a strip 12 miles wide between Waco and the immediate vicinity of Rockwood.

The Rockwood beds are everywhere near the valley floor. Several of the quarry sites have been located on small remnants left in the process of denudation of the valley, and the others have been under the rim of Sand Mountain where the Coal Measures have been covered by the Cretaceous. The Rockwood quarries are not more than fifty feet above the bed of Cedar Creek.

The general quality of the stone from the Rockwood oolite is very good, and it can be said that this stone is satisfactory for building and ornamental purposes, as well as for other miscellaneous uses. The material coming from the present quarry at Aday is practically without fossils and facets of calcite crystals, and carries very few of the thin dark gray streaks that are so common in such stones. This stone weathers quite well and does not stain as badly as similar stone from other localities.

Spout Spring Oolite.—A few years ago in testing the oolitic limestone outcrop at Spout Spring, about 2 miles west of Rockwood, it was found that there was a total thickness of 105 feet of oolitic stone, and the lower 50 feet has been called the Spout Spring oolite. The stone is quite hard, semi-crystalline, and takes a good polish. It is rather attractive in color and gives promise of being a very satisfactory stone for interior use.

Little or nothing is known of the extent of this oolite, since it was not seen at any other point throughout the entire area.

ADAY QUARRY.

This quarry is located about two miles northeast of Waco, and was opened in August, 1924, by the Foster and Creighton Company of Nashville, Tennessee. In 1927, it was taken over by the Rockwood Alabama Stone Company, which operates it at the present time. Production is from a thickness of twenty-four feet of oolitic stone; this is covered by five to eight feet of hard oolitic stone, unfit for building purposes. Several million cubic feet of stone have already been quarried at Aday, and some two or three million feet still remain. The Aday stone is uniformly oolitic and can easily be recognized because of the unusual texture and remarkable uniformity of the stone. The color ranges from buff to gray to variegated. Regardless of the color the texture remains the same. The quarry is located on top of a low hill and comprises some 12 acres. Over at least two-thirds of that area there is little or no stripping of overburden needed, except the removal of humus from the surface and of occasional dirt from seams.

Because of the exceptionally high quality of the Aday stone, efforts are now being made to find a suitable outcrop of similar stone so that new quarries can be opened up when the present supply at Aday becomes exhausted. It is believed that there will be no particular difficulty in finding another quarry site in the same type of stone.

At the Aday quarry is a crane-way having a capacity of about 300,000 cubic feet of stone in quarry blocks. The haul from the quarry to the finishing mill at Rockwood, is about 12 miles, over equal amounts of company-owned and Southern Railway track.

The Aday type stone is characteristic of the area east of Russellville, and a 14 foot layer near the bottom of the face of the Isbell flux quarry about three miles east of Rockwood is of Aday type.

ROCKWOOD QUARRY.

This quarry is located about a mile and a half west of the little town of Rockwood, on the slope of a hill immediately overlooking a small and narrow valley. Although the oolitic stone is at least 55 feet thick in the Rockwood quarry, only about 30 feet of stone is actually being quarried for dimension stone. The stone at Rockwood is somewhat coarser in texture than the Aday stone and layers of fossils are common. The presence of fossils, however, does not detract from the weathering qualities of the stone, nor from its appearance. The color range at the Rockwood quarry is from buff to gray to variegated.

At the present time, the Rockwood quarry has extended its operations to nearly one-third of the workable outcrop. The quarrying operations are extended back into the hill until the cover becomes too great for profitable quarrying. As at the Aday quarry, the cover at the Rockwood quarry consists of a layer of hard oolitic limestone, ranging up to some 15 feet in thickness. A large amount of stone still remains at the Rockwood quarries and it is believed that the operations could be continued by tunnelling under the mountain if necessary.

At the present time the Rockwood and Aday quarries are the only ones in active operation in the district and both of these are being operated by the Rockwood Alabama Stone Company. The Russellville Cut Stone Company and Reed Brothers buy their blocks from the Rockwood Company.

CONCLUSIONS.

In Franklin County there appears to be a sufficient amount of oolitic limestone of both the Aday and Rockwood types, to permit active operation for many years to come. The stone from both quarries is a little harder than competitive limestones from other regions, and the weathering qualities of both Rockwood and Aday types are excellent.

STATE GEOLOGIST OF ALABAMA,
UNIVERSITY, ALABAMA,
March 20, 1939.

DISCUSSION AND COMMUNICATIONS

MAGNETIC SURVEYS IN MICHIGAN COPPER COUNTRY.

Sir: Carl A. Lamey in a footnote on the first page of his article "A Dip-Needle Survey of the Toivola-Challenge Mine Area, Michigan," ECONOMIC GEOLOGY, vol. 33, p. 635, 1938, states that a paper by T. M. Broderick and C. D. Hohl on geophysical methods applied to exploration and mapping in the Michigan copper district was not published until 1929, when it appeared in U. S. Geological Survey Professional Paper 144, pp. 156–168, 1929. It is true, in general, that most of the material which Calumet & Hecla contributed to the latter publication from their files had not previously appeared in print. However, the chapter on experiences with geophysical methods in the Copper Country was presented before the Society of Economic Geologists, Cleveland meeting, December 30, 1927, was submitted to the Editor of ECONOMIC GEOLOGY in January, 1928, and was accepted by him for publication on January 24, 1928. A notice under date of February 25, 1938, was received from the Editor that the manuscript had gone to the printers. The paper was published in ECONOMIC GEOLOGY the following August under the title "Geophysical Methods Applied to Exploration and Geologic Mapping in the Michigan Copper District." Thus the material presented was all obtained during the years prior to December 1927.

T. M. BRODERICK.

CALUMET, MICH.,
April 1, 1939.

REVIEWS

Geology, Principles and Processes. Second Edition. By W. H. EMMONS, G. A. THIEL, C. R. STAUFFER, AND I. S. ALLISON. Pp. 1–451 + xii. Figs. 468. McGraw-Hill Book Co., New York, 1939. $3.75.

The special innovation of this textbook, already appearing to a lesser degree in the first edition, is unquestionably the incorporation of much material not usually introduced into beginning courses. In the eyes of the reviewer, the authors have abandoned the more general discussions, which characterize what may be designated the "classical" approach, and have substituted an emphasis on the more technical aspects of geology. In consequence the "tone" of this text is highly distinctive. This contrast is emphasized by the care taken in clearly figuring such instruments as the aneroid and mercury barometers, the seismograph, and the Brunton compass; accompanying such illustrations are descriptions that really explain what is shown, in place of serving merely as titles. The chapter designated "Probable conditions within the earth" discusses terrestrial magnetism, isogonics, isostasy, and the earth's interior, and it again takes up with great care and a fair amount of quantitative fact the known geophysical data, in place of the broader generalizations more commonly used in describing megadiastrophism and fundamental geophysics.

Noteworthy also are the illustrations in general. Many photographs are new and arresting. The diagrams are especially well designed, as, for example, those in the chapters on the atmosphere, on ground water, and on the ocean. The practice of including inset maps (to locate the region shown in the illustration) is especially commendable, in view of the limited geographic knowledge of beginning college students. Aerial photographs, too, are plentiful and are both instructive and graphic. Photographs of banding in glacial ice, of glacial grooving, and of sea erosion and ocean processes are largely new and striking. For the reviewer, experience with beginning classes leads to skepticism as to the value of the *written*, as opposed to the *pictured* idea; the well-selected illustrations in this book make the text useful, the subject vivid.

Striking is the lack of a section on historical geology. When it is remembered that the *history* of the earth is the most unique contribution

of geology, the absence of such a section becomes especially regrettable. Doubtless this absence reflects a feature of the plan of instruction at the universities where the authors teach, under which historical geology is covered in other, later courses; but, if the reviewer may ground his reflections on practical considerations, the necessity of forcing students to purchase an additional text for what, in many institutions at least, is an integral part of the first year's work militates to a certain extent against the use of this book in such universities.

It is to be hoped that one or two minor shortcomings and errors will be eliminated from later editions, such as the diagram of Chief Mountain (page 376), showing the strata vertical or overturned; the introduction of moraines and dunes as features meriting mention in a chapter on mountains; the lack of scale in several of the diagrams, such as Figures 317 and 404; and several typographical errors such as "Berthould" in the legend of Figure 182. The bibliographies given at the ends of the chapters are not especially well-selected for the beginning student, nor are all footnotes so explicit as to yield their major value. With the exception of these lesser shortcomings, however, and the more important one mentioned in the preceding paragraph, the text is certainly highly satisfactory and ranks among the two or three best of American introductory textbooks.

Perhaps in a review such as this some reflections on the functions of an introductory text are not out of place. In American universities, where there is no tradition that urges the student to wander from school to school, it is doubtful whether the policy of using a text written by the very instructor whom the student sees each day in class is really a favorable plan. To at least expose the student to the stimulus of a different viewpoint from that presented by the instructor, a textbook by another author should be helpful; if several authors have participated, conditions are still better.

One of the chief problems in writing a text is to eliminate extraneous material and reduce illustrative descriptions to the optimum. The average student—and texts must needs be directed at averages, not at exceptions—finds the distinction between significant generalizations and mere illustrative description a difficult one to recognize. It is still a question whether, despite their implications, despite appearances, it might not be well to aid in emphasizing this discrimination by presenting the significant laws and generalizations in large, the illustrative details in finer type, a practice followed, so far as the reviewer knows, in only one American text of the college level.

C. H. Behre, Jr.

The Birth and Development of the Geological Sciences. By FRANK D. ADAMS. Pp. 506; Figs. 79; Pl. 15. Williams and Wilkins, Baltimore, 1938. Price, $5.00.

This fascinating book reflects the author's intimate knowledge of early geological history and is a treasure of information not only for the geologist but for all students of pre-modern thought. It starts with the early Greeks and ends about 1825, when the more rapid advances in geology began. The evolution, not only of geology, but of other sciences is charmingly portrayed. In Prof. Adams' inimitable style there is presented a fascinating vista of thought and interests alien to our times. One is particularly attracted by the "origin or generation of stones"; the origin, nature and properties of gem stones; the "origin of metals and their ores"; "figured stones and the origin of paleontology"; and "quaint stories and beliefs." The many portraits and pictures reproduced from old sources lend particular charm. We wholeheartedly commend it to all geologists.

ALAN BATEMAN.

Miocene Stratigraphy of California. By R. M. KLEINPELL. Pp. 450; Pls. 18; Figs. 14; maps. Amer. Assoc. Petroleum Geologists. Tulsa, Okla. (Thos. Murby, London), 1938. Price, $5.00.

This careful work establishes standard sections for the extensive miocene formations of California based upon detailed paleontologic evidence. It might also be called a text-book on Foraminifera; these are beautifully illustrated by many plates. The sections are compared with typical stratigraphic sequences of the Tertiary of Europe. The stratigraphy and Foraminifera of the Reliz Canyon section are given in detail, and the Chronologic-Biostratigraphic classification is presented. Formational correlations are made within the California Province. There are 174 pages of systematic catalogue of Foraminifera.

Geologische Jahresberichte. Bd. 1. Allgemeine und historische Geologie. 1936–1937. Edited by S. V. Bubnoff. Pp. viii + 508. Gebrüder Borntraeger, Berlin, 1938. Paper 30 Marks.

This is the first volume of a series of publications designed to cover the progress made in geology during periods of two years each. There will be one volume published each year dealing alternately with general and historical geology and with regional geology. The present volume is a collection of articles by prominent European geologists treating in a critical manner of the new theories proposed during the period for the explanation of geological phenomena and of the modifications of old theories suggested. In addition there are brief summaries of new ideas that have

appeared in text books and in discussions in journals, and numerous short descriptions of observations that have enlarged and expanded our geological knowledge, or have modified our interpretation of facts already known.

The book gives an excellent resume of the work done in general and historical geology during the years 1936 and 1937, but the treatment of the subjects dealt with is so condensed that it can serve mainly as a guide to the writings of the authors who have made the contributions that are discussed. Its principal value consists in the excellent classified bibliographies that accompany the different chapters. The thoroughness of the work done in covering the field is indicated by the fact that these bibliographies contain the names of about 2,000 authors, and the number of articles cited in them is over 3,000. It is a good reference book for those who wish to keep abreast of geological progress.

W. S. BAYLEY.

BOOKS RECEIVED.

J. D. BATEMAN.

Coal Mining in Europe. G. S. RICE AND I. HARTMAN. Pp. 369. Figs. 38. U. S. Bur. Mines, Bull. 414, 1939. Price, 50 cts. *A comprehensive study of mining practices in different coal formations under various economic and regulatory conditions compared with those in the United States.*

Étude des Altérations superficielles. Application à l'Exploration géologique et minière. Pp. 112; figs. 6; pls. 4. Pub. du Bur. d'Études Géol. et Min. Coloniales, No. 12, Paris, 1939. Price, 30 fr. *Rock alteration and method of formation of principal types of soils; lateritization, podsolization; application of surface alterations to mineral exploration; a group of papers by French geologists working in Tunis, Madagascar and other colonial possessions; excellent colored plates.*

La flore et la stratigraphie des couches de Ruda dans les environs de Katowice (Bassin Houiller Polonais). STANISŁAW ZB. STOPA. Pp. 18; fig. Inst. Géol. de Pologne, Bull. 7, Warsaw, 1938. *Stratigraphy and paleontology; text in Polish, French summary.*

Bibliographie Géologique de la Pologne. Pp. 51. Edition du Serv. Géol. de Pologne, No. 17, Warsaw, 1937 (1938). *Abstracts in Polish and French.*

Geology and Ore Deposits near Murray, Idaho. P. J. SHENON. Pp. 42; figs. 19; pls. 6. Idaho Geol. Surv., Pamphlet 47, 1938, Moscow. *Lode gold deposits associated with intrusives in the Prichard formation of the pre-Cambrian Belt series; also placer gold.*

Outline of the Geology of the Uruwira Mineral Field, Tanganyika. G. M. STOCKLEY. Pp. 22; geol. map. Tanganyika Geol. Div. Short Paper 22, Dar es Salaam, 1939. Price, 2/50. *Newly discovered mineralized area with promise of commercial lead and gold deposits.*

Contribuições ao Terceiro Congresso Sulamericano de Chimica. Pp. 178; pls.; figs. Inst. de Pesquisas Technologicas de São Paulo, Bull. 17, 1937. São Paulo, Brazil. *Papers relating to physics, chemistry, petroleum and geology.*

A series of papers relating to the geology of Uganda with bibliography and provisional geological map. Pp. 196; figs. 23; pls. 8; maps, 3. Uganda Geol. Surv., Bull. 3, Entebbe, 1939. Price, 10/6. *Rock crystal, tin, tantalite-columbite, lode gold, petrology, physiography, ground water and geophysics; occurrence of gold coated with layers of silica and iron oxides; crystalline gold associated with crystalline quartz.*

Contribuição para o estudos dos Granitos da Serra da Granitos da Serra da Cantareira. Luis Flores de Moraes Rego and T. D. de Souza Santos. Pp. 162; figs. 50; maps (appendix). Inst. de Pesquisas Technolog. de S. Paulo, Bull. 18. São Paulo, Brazil, 1938. *Text in Portugese; summaries in English, French and German.*

Foreign Minerals Quarterly. Pp. 72. U. S. Bur. Mines, Econ. and Statistics Branch, vol. 2, No. 2, Apr. 1939. *Review of the international situation during 1938 with special reference to mineral production and trade of central Europe; various contributors.*

Gmelins Handbuch der anorganischen Chemie. 8 Auflage. System-Nummer 68. Platin. Teil A, Lief. 1 (History and Occurrence), pp. 145. Price, RM 16.50. Teil B, Lief. 1 (Physical Properties), pp. 72. Price, Rm 8.25. Verlag. Chemie, G.m.b.H., Berlin, 1939. *A comprehensive compendium on the history, geological occurrence and properties of the metals of the platinum group.*

Geology and Ore Deposits of the Lordsburg Mining District, New Mexico. S. G. Lasky. Pp. 62; pls. 25; figs. 9; maps. U. S. Geol. Surv. Bull. 885, 1938. Price, $1.25. *Study of complex mineralization in hydrothermal copper-gold-silver-lead deposits.*

Session Extraordinaire de la Société Géologique de Belgique et de la Société belge de Géologie, de Paléontologie et d'Hydrologie. Ch. Stevens. Pp. 61; figs. 32. Liége, 1938. *Guide book for meetings of September 23–26, 1938.*

Instituto de Pesquis. Technol. de Sao Paulo, Sao Paulo, Brazil. Bull. 17. Contrib. ao Terceiro Congresso Sulamericano de Chimica. Pp. 178. *Chemical determinations.* Bull. 18. Granitos da Serra da Cantareira. L. F. de Moraes Rego and T. D. de Souza Santos. Pp. 162; figs. 48; maps. *Occurrence, petrography, economics.* Bull. 20. Inst. de Pesquisas Tecnológicas. Histórico de sua Evolucao (1889–1939). Pp. 102. *Work and equipment.*

Barite Deposits of Virginia. R. S. Edmundson. Pp. 85; figs. 15; pls. 15. Va. Geol. Surv., Bull. 53, University, 1938. *Barite in hydrothermal veins and in pegmatites.*

Mining Industry and Statistics of the Province of Quebec, 1937. Pp. 138; pls. 4; fig. Que. Bur. Mines, Quebec City, 1938. *Review of operations.*

Report of the Geological Survey Department for the Year 1938, Federated Malay States. Pp. 52. Fed. Malay States Geol. Surv., Kuala Lumpur, 1939. Price 25 cts. or –/7. *Tin, ilmenite, china clay, bauxite, tantalum, tungsten, iron, manganese, lode and placer gold.*

The Geology of the Coastal Strip from Big Bay to Professor Creek, Northwest Otago, New Zealand. J. HEALY. Pp. 15; figs. 10. N. Z. Dept. of Sci. and Indust. Research, Wellington, 1938. *Tertiary.*

Copper Resources of New Zealand. J. HENDERSON. Pp. 5. N. Z. Dept. of Sci. and Indust. Research, Wellington, 1939. *No commercial deposits.*

Calcareous Sinter Deposit near Kaeo. R. W. WILLETT. Pp. 3. N. Z. Dept. of Sci. and Indust. Research, Wellington, 1939.

Aerial, Geological and Geophysical Survey of Northern Australia. Pp. 97; maps 16. Canberra, 1938. Price, 5/–. *Rept. of the Committee appointed to direct and control the survey for the period ended 31st December, 1937. Lode and placer gold.*

The Venericardia Planicosta Group in the Gulf Province. JULIA GARDNER AND EDGAR BOWLES. Pp. 72; fig.; pls. 18. U. S. Geol. Surv. Prof. Paper 189–F, 1939. Price, 40 cts. *Forty-four species and subspecies are described and illustrated, 24 of which are new.*

Pleistocene Diatoms from Long Island, New York. K. E. LOHMAN. Pp. 9. U. S. Geol. Surv. Prof. Paper 189–H, 1939. Price, 10 cts. *Tentative correlation of Gardiners clay with Cape May formation.*

The Market for Illinois Oil in 1937 and 1938. W. H. VOSKUIL. Pp. 36; figs. 6. Ill. Geol. Surv., Rept. of Investigations 34, Urbana, 1939.

The Bihar-Nepal Earthquake of 1934. By Officers of the Geological Survey of India. Seismometric Study. C. S. ROY, Burma Meteorological Department. Pp. 391; figs. 17; pls. 36; maps. Mem. of Geol. Surv. of India, vol. 73, Calcutta, Delhi, 1939. Price, Rs. 10–14 or 17/–. *Detailed accounts of earthquake phenomena.*

Ground-water Resources of Northern Virginia. R. C. CADY. Pp. 200; figs. 5; pls. 7. Va. Geol. Surv., Bull. 50, University, 1938.

Outline of the Geology and Mineral Resources of Russell County, Virginia. H. P. WOODWARD. Pp. 91; figs. 9; pls. 13. Va. Geol. Surv., Bull. 49, University, 1938. *Coal, oil, gas, iron and manganese, lead and zinc in Paleozoic rocks.*

Limits of Inflammability of Gases and Vapors. H. F. COWARD AND G. W. JONES. Pp. 146; figs. 44. U. S. Bur. Mines, Bull. 279, 1939. Price, 20 cts. *Brings earlier editions up-to-date.*

The Mineral Industry of Alaska in 1937. P. S. SMITH. Pp. 113; figs. 3; map. U. S. Geol. Surv., Bull. 910–A, 1939. Price, 35 cts. *Gold, silver, copper, lead, platinum metals, tin, coal and petroleum.*

Geophysical Abstracts 93, April–June, 1938. W. AYVAZOGLOU. Pp. 104. U. S. Geol. Surv., Bull. 909–B, 1939. Price, 10 cts. *Brings Bull. 909–A up-to-date.*

SCIENTIFIC NOTES AND NEWS

B. H. PARKER has taken a year's leave of absence from the Colorado School of Mines to make geological investigations for the Argentine government. J. C. HAFF of the University of Wichita will replace Dr. Parker until his return from South America.

On June 15, at the annual convention of the A. W. W. A. at Atlantic City, D. G. THOMPSON and A. G. FIEDLER, senior geologists of the U. S. Geological Survey, were awarded the John M. Goodell Prize for their paper on "Some problems relating to legal control of use of ground water," which was presented at the New Orleans convention and published in the Journal of the Association for July, 1938. The prize, awarded annually for a notable contribution to the science or practice of water work development, was established by Engineering News-Record as a memorial to John M. Goodell, former editor of the Engineering News-Record and of the Journal of the American Water Works Association.

J. R. COOPER has been appointed Associate Professor of Geology at Ohio Wesleyan University, Delaware, Ohio.

The A. I. M. E. held its regional meeting in San Francisco, July 10–15. There were three technical sessions; numerous social events; trips to the Fair; and excursions to Sulphur Bank, Eureka Central and Argonaut mines and to Yuba Dredge No. 20. The program was excellent and well attended.

The Society of Economic Geologists presents the following nominations for officers: PRESIDENT FOR 1941, Alan M. Bateman; VICE-PRESIDENT, W. J. Mead; COUNCILLORS FOR 1940–42, P. Billingsley, J. M. Boutwell, L. C. Snider; REGIONAL VICE-PRESIDENTS, J. A. Bancroft for Africa, J. A. Dunn for India, H. J. C. Connolly for Australia, M. K. Shaler for Europe, G. B. Langford for North America, F. R. Koeberlin for South America.

HANS LUNDBERG, LTD., geophysicists and geologists of Toronto, announce the opening of a United States subsidiary, Hans Lundberg, Inc., in New York.

ARTHUR HOLMES and DORIS L. REYNOLDS announce their marriage at Durham, England, on June 30. Mrs. Holmes, for professional purposes, will continue to be known as Dr. Doris L. Reynolds.

A new mineral "shortite" was announced July 2 by the U. S. Geological Survey. The new mineral, composed of a double carbonate of sodium and calcium, was found and identified by J. J. FAHEY, chemist in the Survey laboratory. Shortite was named in honor of M. N. SHORT of the University of Arizona.

NELS P. PETERSON has been elected Assistant Professor of Mining and Metallurgy at the New Mexico School of Mines, and Geologist for the New Mexico Bureau of Mines and Mineral Resources.

Dr. Peterson has had some thirteen years experience as Engineer, Chief Engineer, Mine Surveyor, Assistant Superintendent, and Superintendent of mining companies in the western states and Mexico.